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[*Continued on page (III) of Cover.*

RECENT DEVELOPMENTS IN TELEGRAPH TRANSMISSION, AND THEIR APPLICATION TO THE BRITISH TELEGRAPH SERVICES

By L. H. HARRIS, M.Sc., Member, E. H. JOLLEY, Associate Member, and F. O. MORRELL, B.Sc., Associate Member.

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SUMMARY

This paper gives details of many of the engineering developments which have taken place in the inland telegraph service of the British Isles during the past few years. Some account is also given of the theory and nomenclature of modern telegraphy and of the application of alternating currents to telegraph transmission.

Chief among the developments is the conversion of the main telegraph system of the British Isles to multi-channel voice-frequency working, which has resulted in the unification of the telephone and telegraph line plant. The introduction and rapid expansion of the private-wire services have also contributed to a renewal of interest in telegraph matters, and engineers have seized the opportunity to adapt for telegraph purposes many of the technical developments of other branches of the telecommunications art.

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(1) INTRODUCTION

In a paper read before The Institution in November, 1932, Mr. R. P. Smith* described the introduction of modern machinery and methods to the inland telegraph service of Great Britain. The developments referred to in that paper have had a far-reaching effect on the service and have been themselves an unqualified success. The main features of the changes were the standardization of the teleprinter for telegraph circuits and the concentration under specially-trained staff of all subsidiary and testing apparatus on racks segregated from the instrument room. Economies in staff and in space, together with increased stability of apparatus, resulted from these changes, but the network of cables and overhead lines remained unchanged.

It had been clear to engineers in recent years† that the use of underground cables solely for direct-current telegraphy was wasteful, and that modern developments in amplifiers and filters could be applied to enable the full frequency range of such circuits to be used.

In 1929 the Comité Consultatif International Télégraphique standardized the speed of the teleprinter, and on that basis in May, 1931, the spacing of the carrier frequencies to be used for voice-frequency telegraph working was also standardized.‡ In November, 1931, the Post Office installed and operated a London–Dundee 12-channel system which had been developed and manufactured in Great Britain and which met completely the requirements of the C.C.I.T. (*Avis* Nos. 511 and 516).§ This 12-channel system was followed in September, 1932, by the installation of a London–Glasgow–Belfast 18-channel system. The experience gained with these

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* See Bibliography, (1).
† *Ibid.*, (13).
‡ *Ibid.*, (3) and (4).
§ *Ibid.*, (6).

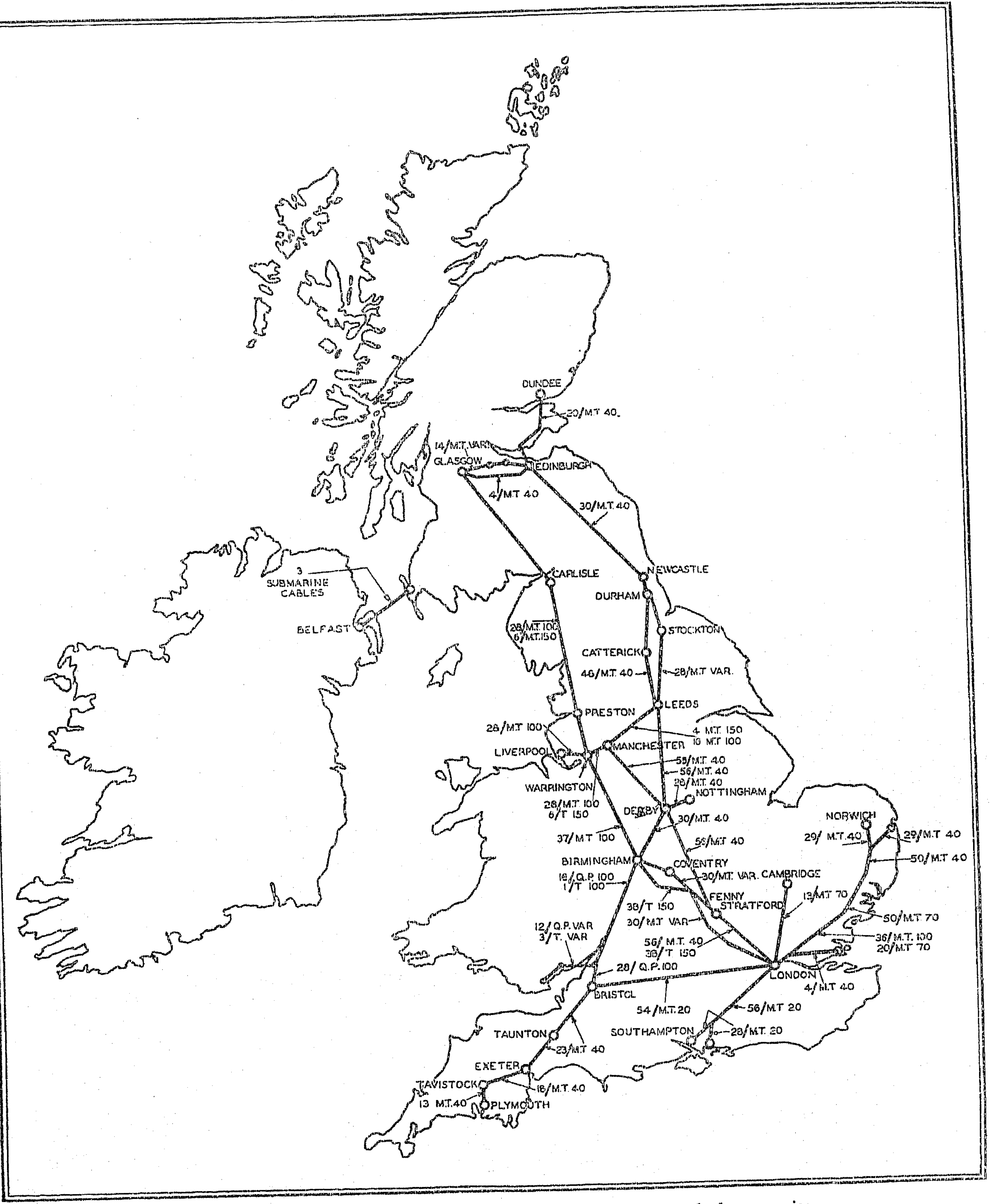

Fig. 1.—Number and type of telegraph conductors released for telephone service.

systems was such as to confirm the anticipated reliability and economy of this system of working, and the complete unification of the telephone and telegraph cable networks was clearly possible. In 1932 the introduction of demand telephone trunk working created a shortage of trunk telephone circuits, and as delay in the specification and provision of new cables had technical and economic advantages it was decided in January, 1933, to convert practically the whole of the inter-urban telegraph network to voice-frequency working and to utilize for telephone purposes the telegraph cables so thrown idle.*

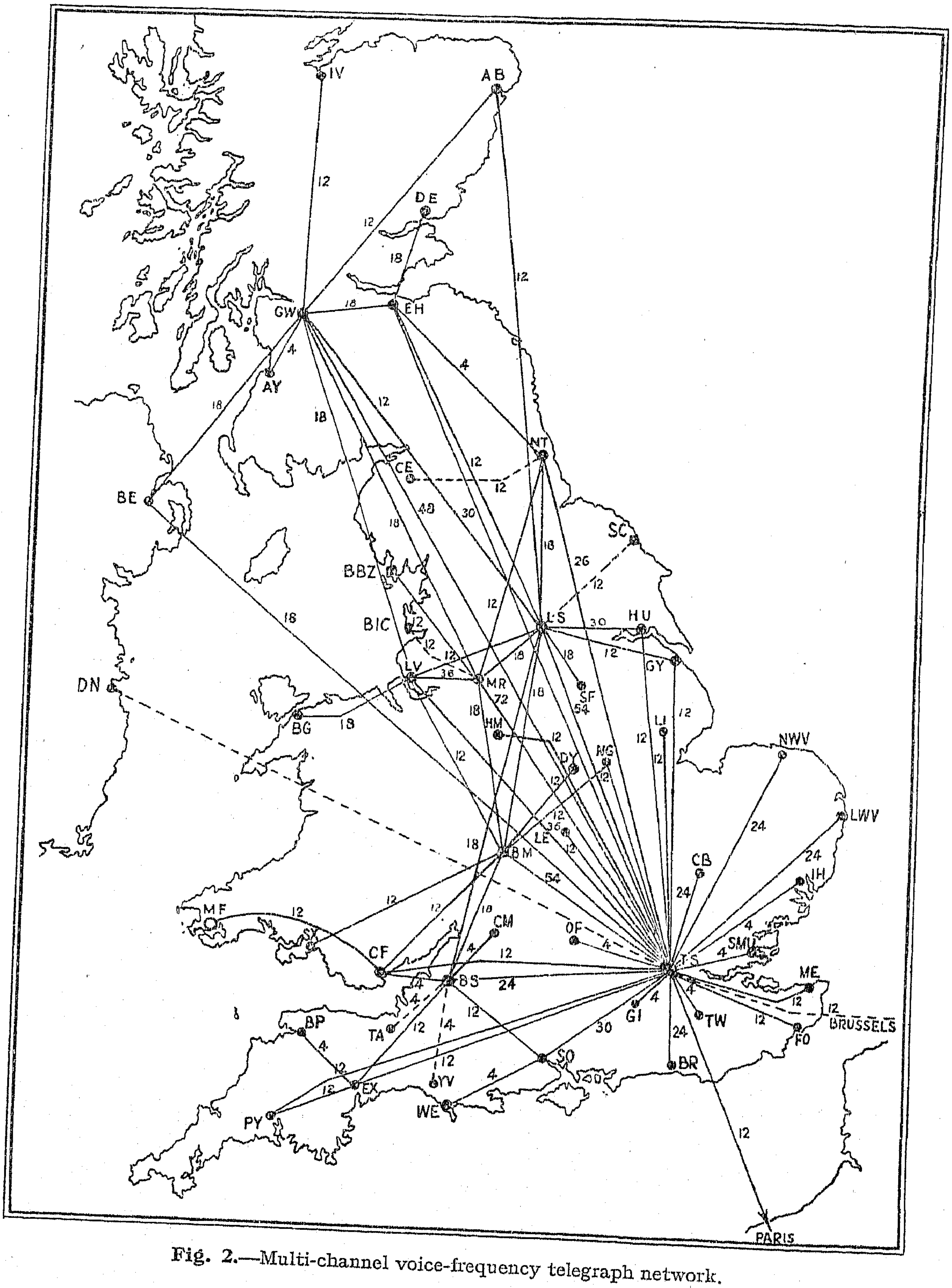

Fig. 2.—Multi-channel voice-frequency telegraph network.

The cable routes released for telephones are shown in Fig. 1, while Fig. 2 shows the extensive network of voice-frequency telegraph channels which replaced the telegraph cable network. Installation of this network commenced in May, 1933, and by December, 1933, 504 channels had been installed; this number increased to 684 in December, 1934, and was added to from time to time until the present total of about 1 000 channels was reached.

This transfer of the telegraph circuits from physical lines to voice-frequency channels completed the revolution that had taken place in the telegraph service, and by 1934 hardly an item of traditional telegraph plant remained in the inland service. Concurrently with these important changes the private teleprinter services which had been introduced in 1932 and which were referred to by Mr. Smith at the time of their introduction, have also prospered. In particular, the simplex point-to-point teleprinter service (tariff A), which includes provision and maintenance of the teleprinters, has been very successful.* There are now more than 300 such circuits, and they produce a substantial revenue.

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* See Bibliography, (43).

Cable companies, news agencies, and newspapers, make considerable use of duplex point-to-point circuits for speeds up to 100 words per minute Wheatstone, or the equivalent. These circuits (tariff B) are provided almost entirely by means of voice-frequency channels, and it is of interest to note that such important circuits as direct extensions of Atlantic cables are numbered among them. Some 58 full-time and 22 part-time circuits of this type are in operation.

Numerous privately-rented circuits remain on physical circuits where these are still available and where the renters have special requirements or use speeds greater than 100 words per minute Wheatstone. An increasing number of newspaper companies now rent telephone circuits on which they provide or rent equipment for alternative speech or pictures and multi-channel voice-frequency telegraphy.

A system of terminating public teleprinter circuits has also been introduced which gives "ancillary" facilities at head offices to improve operating conditions.†

The telex service giving the alternative of teleprinter working to speech over the telephone network, as distinct from a separate teleprinter exchange system without the alternative of speech, has also progressed. One of the features of this service is the "printergram," which enables telex subscribers to transmit and receive their traffic for the inland service direct from their premises to the "printergram" positions in the telegraph office. This service now deals with 20 000 telegrams per week in London alone.

Some controversy has arisen over the relative merits of the two methods of providing subscribers' teleprinter exchange services. While it is agreed that it is a relatively simple matter to provide separate line plant and switches to give a service connecting stations within a limited radius of main centres, it is considered that the telex system has great advantages if a cheap universal system is to be the ultimate aim, with the teleprinter as a mere accessory of the telephone. Important influences affecting the question are the ruling telephone trunk rates and the difficulty of obtaining a good grade of service in the early stages of a separate network.

It may well be that a composite system in which telephone exchange lines or separate telegraph channels are used according to the locality and traffic requirements of the subscribers would be ultimately desirable as combining the advantages of both methods.

One of the latest developments of the private teleprinter services has been the introduction of broadcast systems.‡ In these, facilities are provided and maintained by which a central office of a renter can transmit simultaneously to any reasonable number of out-stations or separately, as required, up to the limit of the number of machines provided at the central office. These systems are finding considerable favour with police services and with news agencies.

It should be mentioned, perhaps, that there is considerable evidence to indicate that in many instances the traffic carried by these new teleprinter services was previously forwarded by post, and the increased revenue arising from these circuits is not offset very appreciably, therefore, by decreased telephone and telegraph revenue. From the renters' point of view the speeding-up of business achieved by substituting teleprinter communication for typewriter communications by post is in itself justification for the moderate expenditure entailed.

(2) FUNDAMENTAL CHARACTERISTICS OF TELEGRAPH TRANSMISSION

(a) Methods of Defining Telegraph Speed, Distortion, and Margin

The electrical communication of intelligence over a transmission link is achieved in normal telegraphy by using an arbitrary time code to represent letters, figures, and signs. Transmission is accomplished by effecting a series of changes in the electrical conditions at the sending end, the signals being characterized by specific time-intervals between successive changes in accordance with the code used. At the receiving end, transmission is completed by the recognition of these time-intervals by the receiver, thereby enabling the characters to be recorded.*

In the proceedings of the C.C.I.T. the operations performed at the transmitter have been given the name "telegraph modulation"; the instants at which the characteristic changes occur are called "characteristic instants of the modulation," and the intervals between these instants "elements of modulation" (*Avis* No. 301: "Definitions Relative to Telegraph Transmission").†

The electrical transmission wave is therefore characterized by changes in amplitude which at the origin are effectively instantaneous but which lose their sudden character during propagation through the line and terminal equipments. On this account the recognition, at the receiving end, of the original time-intervals may be a matter of some difficulty and it is usual to restore the abrupt nature of the changes by means of some form of relay. The latter should have the property of producing locally, instantaneous electrical or mechanical changes at instants corresponding to those at which the amplitude of the received wave is equal to some predetermined value. In general, changes in amplitude of the transmitted wave are accomplished and accompanied by transient effects. If these are of shorter duration than the shortest element of modulation the signals will be unaffected by previous signals under all conditions. Assuming this to be so, then in the absence of external disturbing influence the response of the system to a modulation will always be the same and the instantaneous changes produced by a perfect relay will always occur with a constant delay after the corresponding operation at the origin of transmission. Under these circumstances the received signals would be in exact accordance with the operation of the transmitter and the system would be telegraphically distortionless. Actually, distortionless transmission is still obtainable when the duration of the transients exceeds the shortest modulation element, it only being necessary that transients due to one modulation shall have died away before the receiving relay operates in response to the next following modulation. This requirement sets a theoretical maximum transient time equal to twice the duration of the shortest modulation element. In practice such perfection is neither obtainable nor essential, but in all systems there is some limit to the permissible departure of the received signals from perfect agreement with those at the origin.

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* See Bibliography, (48).

† *Ibid.*, (49), for full description.

‡ *Ibid.*, (28).

* See Bibliography, (10), (11), and (12).

† *Ibid.*, (6).

Telegraph speed.

The degree of imperfection is to a large extent dependent upon the relation between the duration of the transient effects and that of the shortest element of modulation. These two factors are therefore of primary importance in telegraph transmission, since the maximum rate at which information may be passed over a channel is inversely proportional to the duration of the shortest element of modulation. These facts have led to the use of the shortest element of modulation as the basis for the numerical expression of telegraph speed, which is defined as the inverse of the duration (expressed in seconds) of the shortest element of modulation. The unit of telegraph speed therefore corresponds to one minimum element per second and is called the " baud." This definition is readily applicable to Wheatstone, Baudot, and normal teleprinter systems, and can probably be made to apply to all telegraph systems, provided due care is taken in any particular case to determine the appropriate meaning of the phrase " shortest element of modulation."

Telegraphic distortion.

The process of reproducing the characteristic instants of modulation at the receiving end by means of some form of relay has been given the name " restitution of modulation," while the time-interval between an instant of modulation and the corresponding instant of restitution is called the " restitution delay." As already stated, a telegraph circuit having a constant restitution delay is telegraphically distortionless, but in practice these delays may vary appreciably from one instant to another. With excessive deviation from constancy the correct interpretation of the received signals is either impossible or involves unduly meticulous adjustments. Numerically, the degree of distortion of the reproduced signals is expressed as the ratio of the differences observed between the restitution delays to the duration of the shortest modulation element. In practice it is usual to refer only to the greatest of these differences.

It will be seen that this definition refers to a complete telegraphic link which may be of utmost simplicity (e.g. a relay itself) or may be a complex system of transmission paths and apparatus. In either case it refers only to a particular set of conditions at the origin and the consequent conditions at the input and the output of each subsequent path or piece of apparatus comprising the system. As long as this is remembered, the definition has a useful practical meaning and is therefore becoming widely used. The C.C.I.T. has also given definitions for the distortion of a receiver and of a transmission path itself, but it is considered that these are less satisfactory in practical interpretation since the definition of distortion is such that it can only be applied to a complete telegraph link including specific modulating and demodulating components.

It has been found convenient to classify distortion as follows:—

(i) *Characteristic.*—Distortion occurring consistently with any given series or combination of signal elements.

(ii) *Fortuitous.*—Distortion due to irregularities in any part of the circuit or apparatus.

(iii) *Bias.*—Distortion due to either the marking or the spacing elements of the signals being lengthened owing to asymmetry in the transmitting or receiving apparatus.

Margin of receiving apparatus.

The margin of a telegraph receiver is measured as the maximum distortion which may occur on any or all the signals which may be applied to it, compatible with perfect registration of all the symbols for which it is designed. Margin has been classified as follows: The " theoretical " margin is the margin calculated in accordance with the constructional data of the mechanism, assuming perfect conditions. The " effective " margin is the margin actually measured on the apparatus. The " nominal " margin is the minimum allowable value of the effective margin of machines in standard adjustment (*Avis* No. 302).*

Transmitted telegraph signals may be imperfect at their origin owing to transmitter distortion. This can be measured and given a numerical value as a ratio, in the same way as is done for telegraph distortion generally, by comparing the actual instants of modulation with those which would occur with perfect signals.

These definitions and terminology, together with the development of apparatus for measuring the quantities defined, have resulted from the desire on the part of engineers to put telegraph practice on a sound scientific basis. A large measure of success has been obtained, and apart from research and testing work the measurement of channel distortion and teleprinter margin is now a matter of routine in the maintenance of the inland telegraph service.†

(b) Transmission Characteristics of Telegraph Systems as affected by Operating Requirements

The rate of operation of a telegraph channel may be defined as the rate at which information is passed over the channel. This is usually expressed in words per minute, each word for this purpose being taken as consisting of five letters and one spacing signal. In ordinary telegraphy in which the letters, for the purpose of transmission, are represented by trains of impulses according to a predetermined code, the communication link has to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler the line requirements and the narrower the frequency band required, and therefore the signalling code should be such as to be as economical as possible in this respect. Table 1 illustrates the relative efficiencies of various systems of telegraphy from this point of view, for plain English.

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* See Bibliography, (6).

† The whole of the remarks and definitions in this section of the paper refer to the normal forms of telegraphy, making use of progressive codes. Where frequency, and not time, is the basis of discrimination, the foregoing definitions are not necessarily applicable.

At one end of the scale is cable code, a 3-position code developed for working on long transoceanic cables, and at the other picture telegraphy, whereby a facsimile reproduction of the original matter is obtainable. Intermediate is the Siemens–Hell writer,* a form of picture telegraphy in which greater reliability is secured on radio links subject to disturbances, at the expense of a great increase in the baud speed.

It is of interest to note the connection between speed, accuracy, and the nature of the code used. Maximum speed is obtained when the number of combinations which it is possible to transmit is restricted to the normal alphabet. Thus with 5-unit systems the possible combinations are limited to 32. With the Siemens–Hell system the number of combinations which can be effectively drawn by the receiver must be many hundreds, but since use is only made of those having alphabetical significance the system must be somewhat wasteful of line time (or band width). In the case of picture telegraphy the number of possible combinations that can be transmitted is practically infinite, and to use such a method for transmitting merely a limited number of alphabetical signs is essentially wasteful so far as line time (or band width) is concerned. If, instead of speed, accuracy is considered, the order of merit of the above systems is reversed. Thus an incorrect element in the case of 5-unit code alters the printed character from one letter of the alphabet to another. In the case of the Siemens–Hell system a mere irregularity results which does not render the character illegible. In the case of picture telegraphy an incorrect element might well pass unnoticed.

Table 1

System	Transmission speed for a signalling speed of 1 character per sec. (bauds)
Cable code	3·3
Multiplex (5-unit code)..	5 to 6 (depending on method of speed correction)
Teleprinter (start-stop)..	7 or 7·5
Hughes	7·5
American morse ..	7·7
International morse ..	8·6
Siemens–Hell writer ..	100
Picture telegraphy ..	100 to 300

Considerations of operating and engineering economics have led to the standardization of teleprinter working in the British inland service. A speed of 50 bauds has been fixed as standard by the C.C.I.T. for teleprinter communications (*Avis* No. 651),† and this is equivalent to a maximum possible output of 71·5 words per minute for 7-unit working and 66·6 words per minute for $7\frac{1}{2}$-unit working. Experience has shown that little is to be gained in the way of a sustained increase in operator output by an increase of the maximum output of the machine much above 60 words per minute. From the point of view of operator output, therefore, the teleprinter working at 50 bauds satisfies requirements, and although it is not quite so efficient in ratio of words per minute to bauds as some systems this disadvantage is outweighed by its relative simplicity and feature of direct instrument-to-instrument communication.

Although the economic use of line time is important, it is secondary to economic operating, and at present the tendency is to obtain operating economies by increased expenditure on plant. This tendency is likely to continue as technical developments become available for telegraphic application. The present interest in wide-band cables and television, for example, may lead ultimately to high-speed automatic facsimile methods being introduced in which, on heavily-loaded routes, the elimination of operating would more than repay the high cost of apparatus and the inefficient use of band width which such a method would entail.

(c) Transmission Characteristics of Telegraph Apparatus

The transmission characteristics of the telegraph apparatus itself, as distinct from those of the telegraph system, are related to the formation of the signals at the transmitter, their repetition at repeaters, and the translation of the signals into printed characters at the receiver.

Transmitters.

A telegraph transmitter in general consists of a mechanical means for producing the characteristic modulations of the telegraph transmission. An ideal transmitter would perform these modulations instantaneously and at the exact instants required by the code. The performance of a transmitter is measured by the degree to which it approaches this ideal.

In teleprinters the movements of the transmitting contacts are controlled by rotating cams. Such cams are cut to a high degree of precision, and the time displacement of any instant of modulation from its proper position, due to inaccuracies in the cams or co-acting parts, does not usually exceed 5 per cent of the shortest modulation element. Wear or maladjustment may, however, result in irregular distortion. The methods in use in the British Post Office for checking the performance of transmitters in respect of the foregoing points are dealt with later.

The timing of the modulations performed by a transmitter is also affected by the speed at which it is being driven. Variable speed will result in irregular distortion. All printing telegraph systems, however, include means for preventing or limiting cumulative distortion due to incorrect speed. In teleprinters the driving motor is governed to an accuracy of ± 0·5 per cent of a given speed, and, while normally the speed difference between machines is not greater than 1 per cent, satisfactory working is usually possible with appreciably greater speed-differences. A speed error of 1 per cent corresponds to 6 per cent distortion of the modulation corresponding to the commencement of the stop signal.

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* See Bibliography, (33).

† *Ibid.*, (6).

Receivers.

All telegraph receivers are adapted to permit a certain amount of distortion in the received signals. As already stated, the limiting value for this distortion is termed the "margin" of the receiver. The margin is, in the first place, governed by the duration of the discriminating period when the receiving mechanism tests the polarity of the incoming signal. In most teleprinters the discrimination is performed mechanically, but it may be performed electrically. Whether performed mechanically or electrically, the period required for discrimination can be as short as 2 milliseconds. Any reduction below this value will have an inappreciable effect on the practical margin of the machine. A discrimination period of 2 milliseconds gives a theoretical margin at 50 bauds of 45 per cent, while a reduction of the discrimination period to 1 millisecond would only increase this to 47·5 per cent. The theoretical margin is inevitably reduced by reason of small inaccuracies in manufacture, wear of moving parts, irregularities in the operation of the electromagnet and start-stop clutch, and speed fluctuations. The value fixed by the C.C.I.T. for practical purposes is 35 per cent (*Avis* No. 331).*

Incorrect speed will result in a reduction of margin, a speed error of 1 per cent being equivalent to a loss of margin of approximately 5·5 per cent on the fifth code element.

One of the new questions proposed in 1934 by the C.C.I.T. for study was the relation between the effective margin of a machine and the text distortion with which it will operate satisfactorily. In tests on voice-frequency multi-channel equipment it has invariably been found that a machine having a certain margin, measured by varying the instants of modulation with respect to the start signal, will operate without error on a circuit having the same figure of distortion, in spite of normal transmitter distortion and speed difference. This apparent discrepancy can, however, be shown to be due entirely to the differing conditions of testing and operating and to the general nature of the C.C.I.T. definition of distortion. The C.C.I.T. definition gives a measure of the efficiency of a telegraph circuit without specific reference to the instruments with which it is used, and therefore takes no account of the special conditions applying to the start signal of a teleprinter, which is preceded by a stop signal at least 1½ units in length. The margin of the machine is measured by the maximum distortion on any element which will not cause a wrong selection, irrespective of the position of the element and the conditions of the preceding elements. It is frequently impossible, and, in any case, extremely unlikely, that the maximum distortion will occur on that element on which, under the same conditions, the permissible distortion is a minimum. On keyboard operation the limitations of the C.C.I.T. definition are even more apparent, and therefore measurements made in accordance with the definition result in a pessimistic estimate of the overall margin of the channel.

The above does not detract from the practical utility of margin measurements of machines or of distortion measurements of circuits. These measurements in themselves ensure separately, correct adjustment of machines and circuits, and the present difficulty of exact correlation is, in practice, of only secondary importance.

Detailed examination of the margin characteristics of various types of telegraph apparatus have been made, and a number of references to this subject will be found in the Bibliography.*

Regenerative repeaters.

Ordinary telegraph repeaters are well known and do not call for special comment. A regenerative repeater consists essentially of a telegraph receiver which, instead of using the translation to print a character, uses it to initiate a new transmission of the telegraph signal, devoid of distortion. A receiving perforator and automatic transmitter can therefore be used together as a regenerator. The aim in regenerative repeaters has been to reduce the translation and re-transmission operations to the utmost possible simplicity. A regenerator required to work on a teleprinter circuit will naturally operate on the start-stop principle, and broadly its transmission characteristics will be similar to those of a teleprinter receiver and transmitter. In one form of start-stop regenerative repeater,† in which the translation of the received signals is performed electrically by arranging for the discrimination device to control the grid of a thermionic valve, an almost instantaneous discriminating period is possible, enabling the maximum amount of receiving margin to be obtained.

Errors of speed affect the margin and output distortion of start-stop regenerative repeaters in a similar manner to that described for teleprinters, but there is, however, one special case which requires mention. This occurs when the regenerative repeater is running slower than the sending transmitter. This causes the rest period between letters on the repeater to be shortened, so that the duration of the stop signal sent out is reduced. With 7-unit sending from an automatic transmitter, the stop signal is only one unit, and a reduction of its length due to speed difference might cause faults in the transmission, by reason of the greater distortion the shortened stop signal would suffer in transmission over the next repeater section. The shortest-length stop signal which the regenerator can send under the most unfavourable conditions is governed by the speed of rotation of the translator shaft. In teleprinters working on the 7-unit system the receiving shaft usually completes a revolution in 6·5 units. In the case of the regenerator mentioned, the time of a revolution is increased to 6·8 units, so that the shortest possible stop signal is equal to 0·8 of a unit signal. With 6·8-unit reception the maximum permissible speed-difference is 3 per cent, allowing for 2 per cent on the teleprinter and 1 per cent on the regenerator. It has been suggested to arrange that the transmitter of the regenerator is automatically speeded up when receiving from a fast teleprinter, in order to prevent mutilation of the stop signal. This involves some complication of the repeater, and the difficulty can be entirely avoided by using 7·5-unit transmission as is done in Great Britain. With this point in mind, the C.C.I.T. in 1934 recommended that the duration of the stop signal could be either 1 or 1·5 units (*Avis* No. 651).*

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* See Bibliography, (6).

* See Bibliography, (4), (32), and (34).

† *Ibid.*, (29).

(3) APPLICATION OF VOICE-FREQUENCY METHODS TO SERVICE REQUIREMENTS

(a) Voice-Frequency System

Practically the whole of the inter-urban telegraph network has been converted from direct-current to alternating-current transmission using multi-channel voice-frequency equipment. Details of the voice-frequency apparatus used to build up this network have already been published,† and it is therefore proposed in this paper to give only the essential outlines of the system.

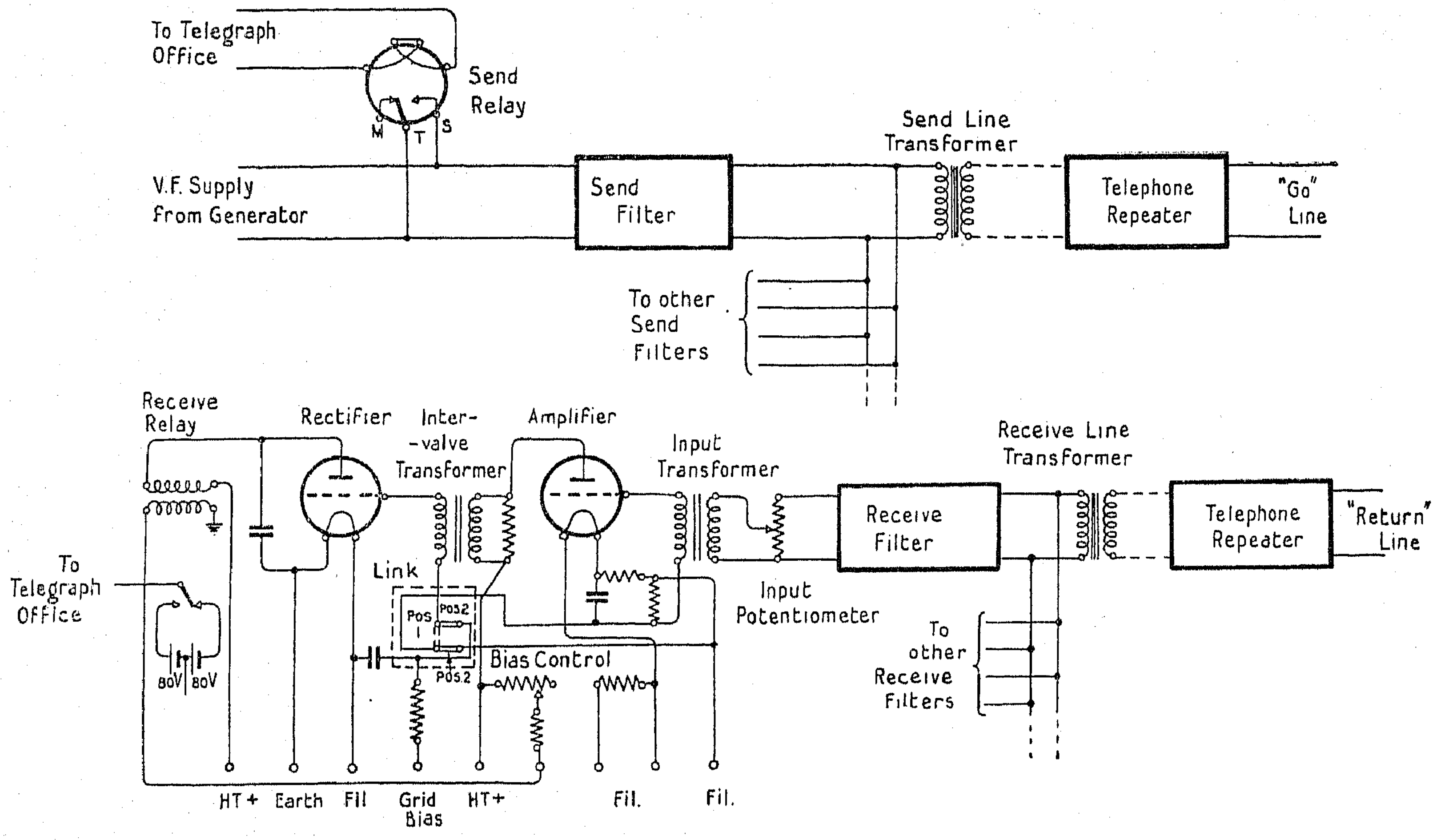

Fig. 3.—Schematic diagram of a voice-frequency send and receive channel.

The 18 frequencies used are the odd multiples of 60 cycles from 420 to 2 460 cycles. These are generated by a multi-frequency machine, driven by a motor fitted with a centrifugal governor which regulates the field current and controls the speed to within ± 0·25 per cent.

The output is permanently adjusted to 1 volt for each frequency, and ten 18-channel systems can be fed from one machine. The generators are provided in pairs, one working and one reserve, and in addition emergency reserve machines are held at the London and Glasgow centres.

A schematic circuit diagram is shown in Fig. 3. At the input to the sending filters are resistance coils by means of which the output to line may be adjusted. The outputs of the 18 single-section "send" filters are commoned to the apparatus side of the line transformer, the other winding of which is connected to the "go" side of the 4-wire cable circuit. At the receiving end, similar but double-section filters are commoned to the line transformer, the outputs of which are taken to the respective amplifier-rectifier panels via a potentiometer calibrated in decibels. The amplifier-rectifier is so designed that for all input levels above that required to cause grid current to flow in the rectifying valve the bias of the amplifier valve and its gain are automatically adjusted to compensate for variations in the level of the incoming signal. This characteristic is important as it ensures that the telegraphic distortion will not change with ordinary changes in line level, and even with big changes in level will not exceed workable limits. As a result of this method of providing automatic regulation it is preferable that the idle condition of the channels should correspond to the continuous transmission of tone and that the signals should consist merely of interruptions in this tone. This arrangement has the added advantage that the best running condition of the valves is obtained and also that an interruption to the 4-wire circuit is made immediately obvious by the racing of the teleprinters and by the continuous operation of the calling lamps and bells on the speaker channels.

(b) Line Conditions

The circuits normally used for multi-channel telegraphy are identical with zero-loss 4-wire telephone circuits except that the echo-suppressors and the 4-wire terminations are disconnected and the two sides of the circuit completely separated so that the same 18 frequencies can be used in both send and receive sides. The line levels for working on zero circuits are shown in

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* See Bibliography, (6).

† *Ibid.*, (2), (16), and (17).

Fig. 4. The particular line arrangements shown are not essential, as 4-wire circuits with an overall attenuation up to 15 db can be operated; for example, in the case of the London–Brighton systems non-repeatered circuits of 6·5 db are used. The advantage of using zero trunk telephone circuits lies in the ease with which replacements can be made in the event of interruption of the working circuit. The organization is such that the average time taken for the change is 8 minutes.

(c) Power Supplies

The supplies necessary for voice-frequency equipment, apart from all-mains sets, are the usual 24-volt and 130-volt repeater-station supplies for filaments and anodes respectively, and in addition a ± 80-volt telegraph supply. The 24-volt supply for the multi-frequency generator motor may be separately fed from a motor-generator set or from rectifiers, but the common field of the stator of the generator must be fed from the filament battery. The 80-volt telegraph supply can be taken from existing telegraph batteries when conveniently situated, or, as is more generally the case, from a motor-generator set with the two 80-volt generators and motor on the one shaft.

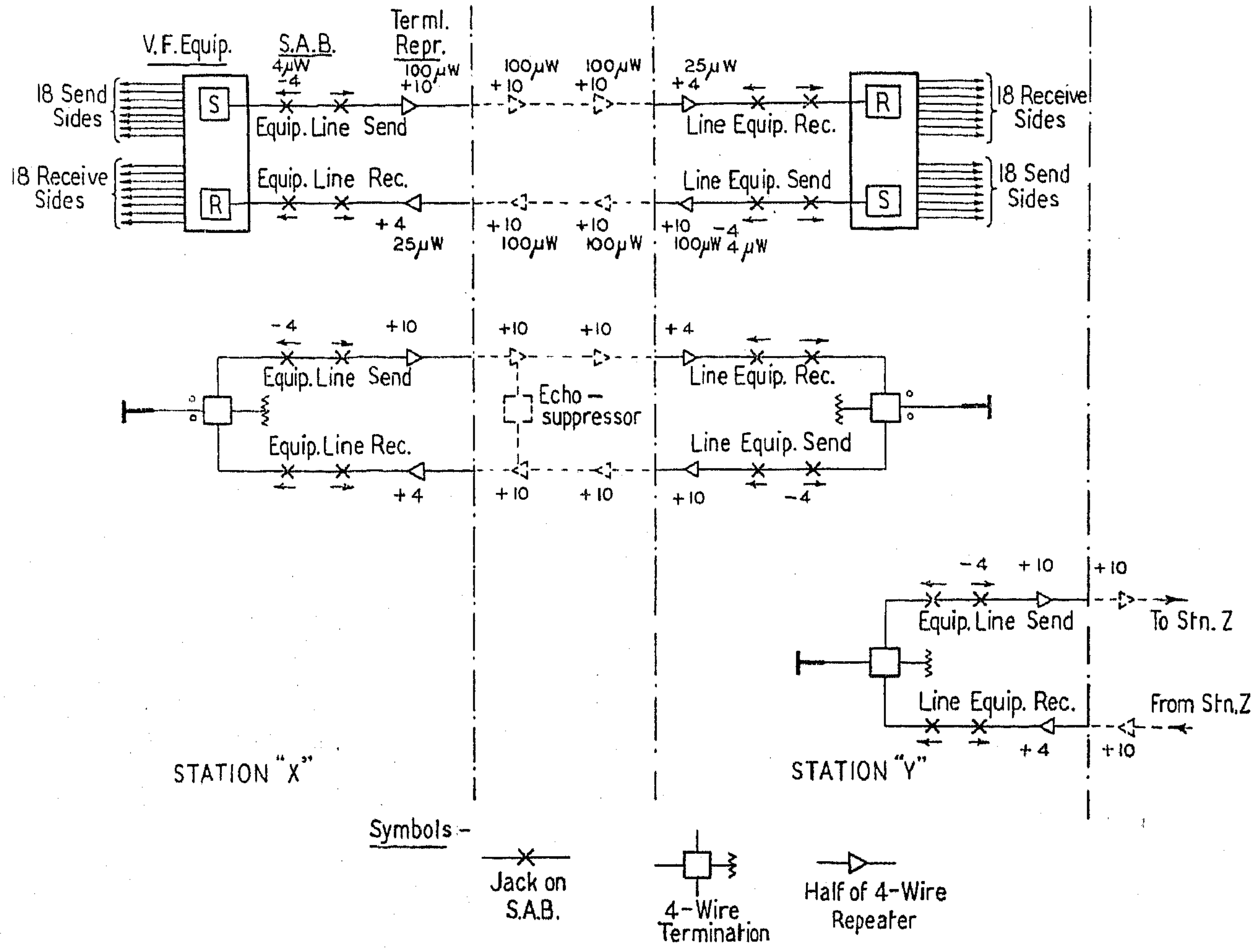

Fig. 4.—Four-wire circuit and line levels.

Arbitrary telegraph level chosen = 10 microwatts per channel at a point in the circuit equivalent to telephone zero.

It should be mentioned that a great deal of progress has been made towards the standardization of ± 80 volts for all telegraph purposes and the elimination of ± 24, ± 40, and ± 120 volts, which were employed for local- and main-line batteries under the former d.c. conditions.

(d) Maintenance

The maintenance of the voice-frequency network is carried out by normal repeater-station staff, who, it has been found, soon become familiar with the apparatus. Channels are tested at present at 3-weekly intervals, one channel per system being tested each day to ensure a daily watch on the level of the 4-wire circuits. Engineering speaker circuits (teleprinter) are provided between important centres to ensure close co-operation in testing.

In the case of the public telegraph circuits, channels are only handed over by the commercial staff for engineering attention after it has been proved as far as is possible by teleprinter tests that it is the channel itself and not a terminal teleprinter that is at fault. The present average duration of interruptions of commercial circuits due to causes attributed in any way to the voice-frequency system is between 4 and 5 minutes per week per channel. In the case of private-wire renters, the renters report faults by telephone directly to the voice-frequency terminal.

A relay test table is provided at all centres, and also in all but the smallest centres a test bay is included which embodies line and filter testing panels as well as a telegraph distortion measuring set.

In Fig. 5 the installation progress of the voice-frequency network is shown from June, 1932, when only one system between London and Dundee existed, to the present time. Several further systems extending to Scotland and Belfast were installed from time to time, and at the beginning of May, 1933, the conversion of the whole of the northern

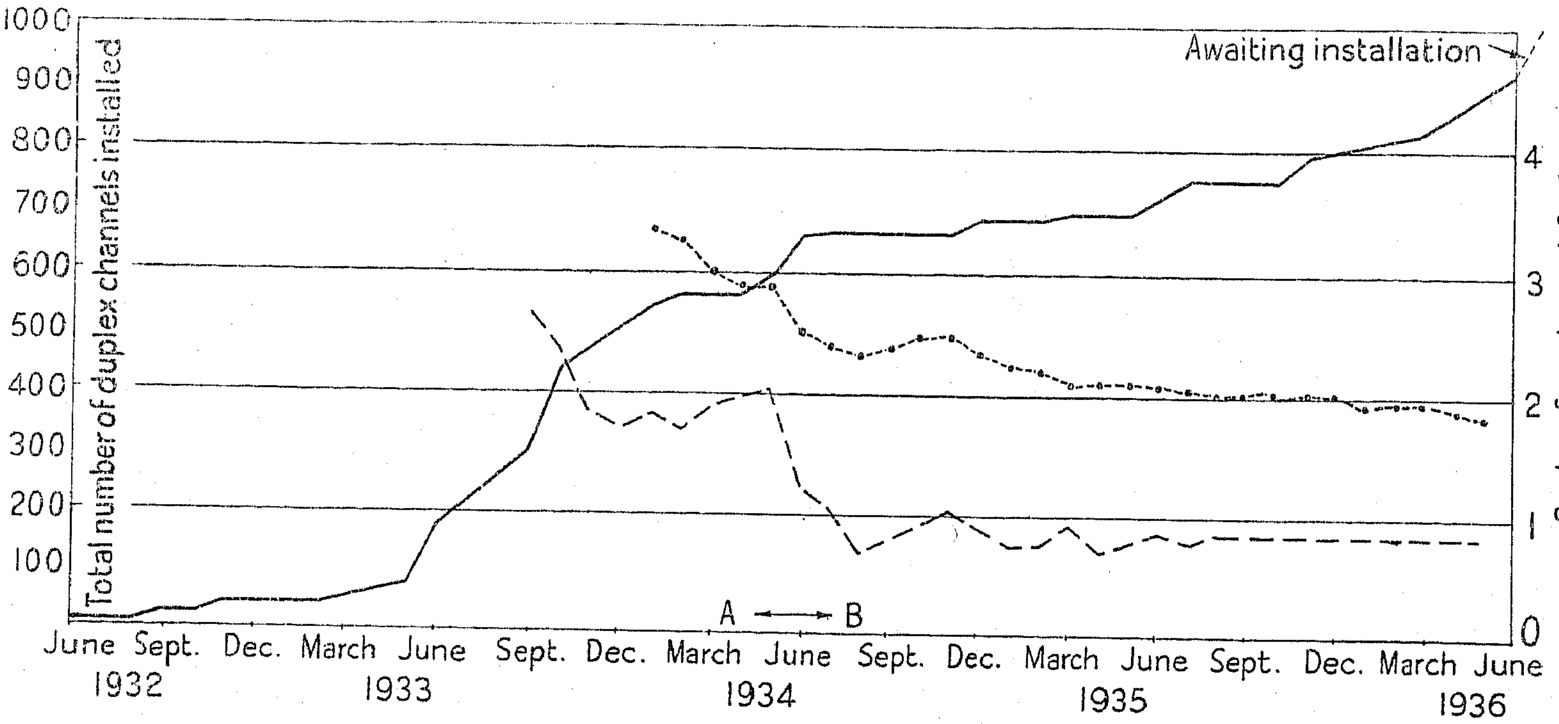

Fig. 5.—Progress chart of voice-frequency telegraph system of British Isles.

———— Total number of duplex channels installed.
– – · – – · – – Decrease in average maintenance labour costs (arbitrary scale).
— — — — Decrease in average faults per channel (arbitrary scale).
A–B denotes period during which platinum-iridium contacts of receiving relays were changed to copper-palladium and the teleprinter circuits were modified.

telegraph system was commenced. This conversion was carried out in 13 months, and has been supplemented steadily since then to meet private-wire and increased traffic requirements and to provide uniformity in the method of working to the smaller towns. Fig. 5 shows also the improvement obtained in apparatus-fault liability and in maintenance labour costs.

In making the preliminary financial examination of the scheme for the complete transfer of the telegraph system to voice-frequency working the estimated engineering maintenance labour costs per channel were cut, as it was thought, to the bare minimum, and it is all the more gratifying, therefore, to find that these costs have now fallen 20 per cent below the estimated figures and 40 per cent below the costs for January, 1934.

Further reduction is anticipated as the staff become still more familiar with the system, and experience enables improvements to be made in methods and in apparatus.

(e) Commercial Facilities

As far as possible the voice-frequency telegraph network has been built up to enable teleprinter circuits to be made up readily for any of the public or private wire services without regard to the position of, or distance between, the terminal towns. One of the outstanding advantages of a standardized voice-frequency network is that all channels are identical and can be connected together without previous preparation to provide any desired routing. The direct-current ends of the channels are all terminated on the control boards in the telegraph instrument rooms for this purpose. On the major routes a speaker channel is provided for communicating between the supervising staffs at the more important instrument rooms to facilitate testing and "special event" work. The ease with which the large amount of special-event work can be carried out on the new system is remarkable. Some of these temporary arrangements are very extensive; for example, Fig. 6 gives the circuits required for the Doncaster Race Meeting. The arrangements frequently include "omnibus" circuits by which, for example, messages transmitted from one teleprinter are received simultaneously

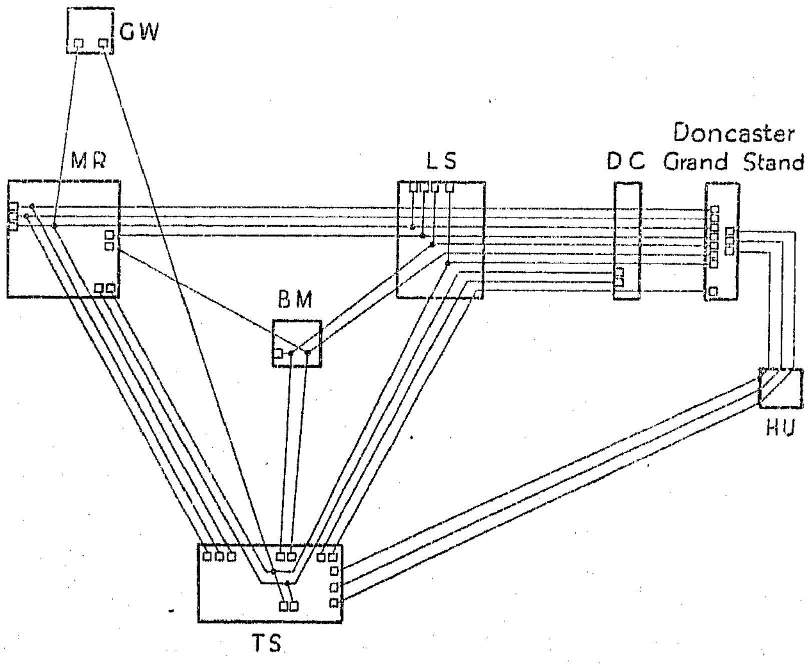

Fig. 6.—Special-event network for Doncaster Race Meeting.

● Indicates combiner unit.
☐ Indicates teleprinter.

on teleprinters situated at Leeds, London, Manchester, and Glasgow. In such cases "combiner units" are plugged into circuit at the appropriate control boards. These units operate on the principle shown in Fig. 7, and have proved a very successful solution of the omnibus-circuit problem. The four operating windings of this unit are connected to the "receive" sides of the channels forming the omnibus circuit, and signals in any one of these channels result in their retransmission from the contact of the unit over all the "send" sides of the channels in parallel. In order to maintain overall neutrality of the relay when less than four circuits are required it is arranged that the equivalent current for each unused winding is obtained from the inner springs of the jacks used for making up the circuit.

Complete facilities are provided by means of transfer circuits between the control boards and the concentrator for connecting any voice-frequency channel to any teleprinter position in the instrument room, or alternatively to any physical line circuit via appropriate panel-mounted relay or balancing equipment.

Adjacent to the control board, test and observation positions are provided, and also synchroscopes for checking the speed of either the local or the distant teleprinter motors. The test and observation positions consist of small steel-frame tables carrying a teleprinter and a panel fitted with milliammeters and keys. The tables are wired to test jacks on the voice-frequency control board and can be connected with plugs and cords to any channel without interrupting the service on that channel. According to the position of the keys the signals passing on either the send or the receive sides of the channel can be observed, or the circuits can be terminated at the test position and operated to the near or to the distant teleprinter.

It will be seen from the foregoing that through circuits are provided by the coupling of channels at the voice-frequency control boards, which, in effect, connect the send and receive relays of the channel on one route to the receive and send relays respectively of the channel on a second route. Theoretically it would be possible to design a network in which all coupling of channels could be carried out by means of filters. Such a scheme would have the advantage that relays would be unnecessary at the intermediate stations but would, in the case of an intricate network, such as that of the British Isles, lead to very complicated and non-flexible filtering arrangements. Under cable-breakdown conditions it is a tremendous advantage to be able to couple channels from one system to another, irrespective of their frequencies. The balance of advantage would probably, however, be with the filtering method in certain simple cases, such as, for example, on a very long and important international circuit in which end-to-end channels between capitals were required in addition to channels from these ends to an intermediate capital. Such channels might be required to form parts of still longer circuits, and the small constant distortion introduced by the filters might well be preferable to the additional relays that would be in circuit and under third-party maintenance if separate systems with relay coupling were adopted.

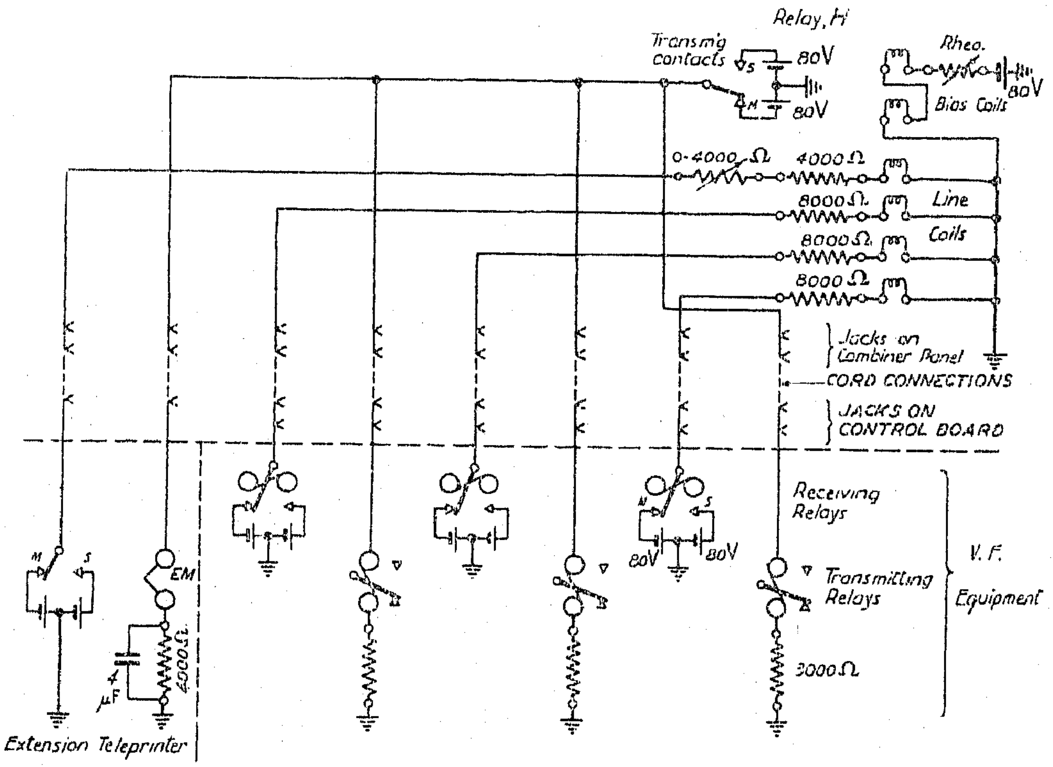

Fig. 7.—Circuit diagram of combiner unit connected to three voice-frequency channels and one extension.

(f) Effect of Linking Channels on the Overall Distortion of a Telegraph Circuit

This problem has received a considerable amount of attention during the past few years. The C.C.I.T. has had to consider the question in regard to international circuits, and of course the question is one of first importance in the consideration of switched telegraph systems.

The C.C.I.T. has laid down (*Avis* No. 331)* that the total distortion of a telegraph circuit must not exceed 28 per cent and that the distortion of each link in the circuit should not exceed 10 per cent when measured as a separate circuit. The study of the subject is being continued, but so far the theoretical examination is not of material value compared with the knowledge and experience which have been gained in the field.

In Great Britain the interest in the question relates chiefly to the linking of channels of the voice-frequency network. Much information has been acquired on this particular aspect of the subject, but it must be remembered that the results apply only to the particular design of system which has been standardized in this country and not to voice-frequency systems generally. If on this system the overall distortion of a considerable number of circuits consisting of one, two, three, etc., channels linked together be measured and an average taken for each number of links, these average figures will be approximately additive. If, on the other hand, single examples are taken so that the separate distortions of a number of particular channels are first measured and then the overall distortion of them all linked, it will be found that the result will seldom agree with the arithmetic sum of the separate distortions.

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* See Bibliography, (6).

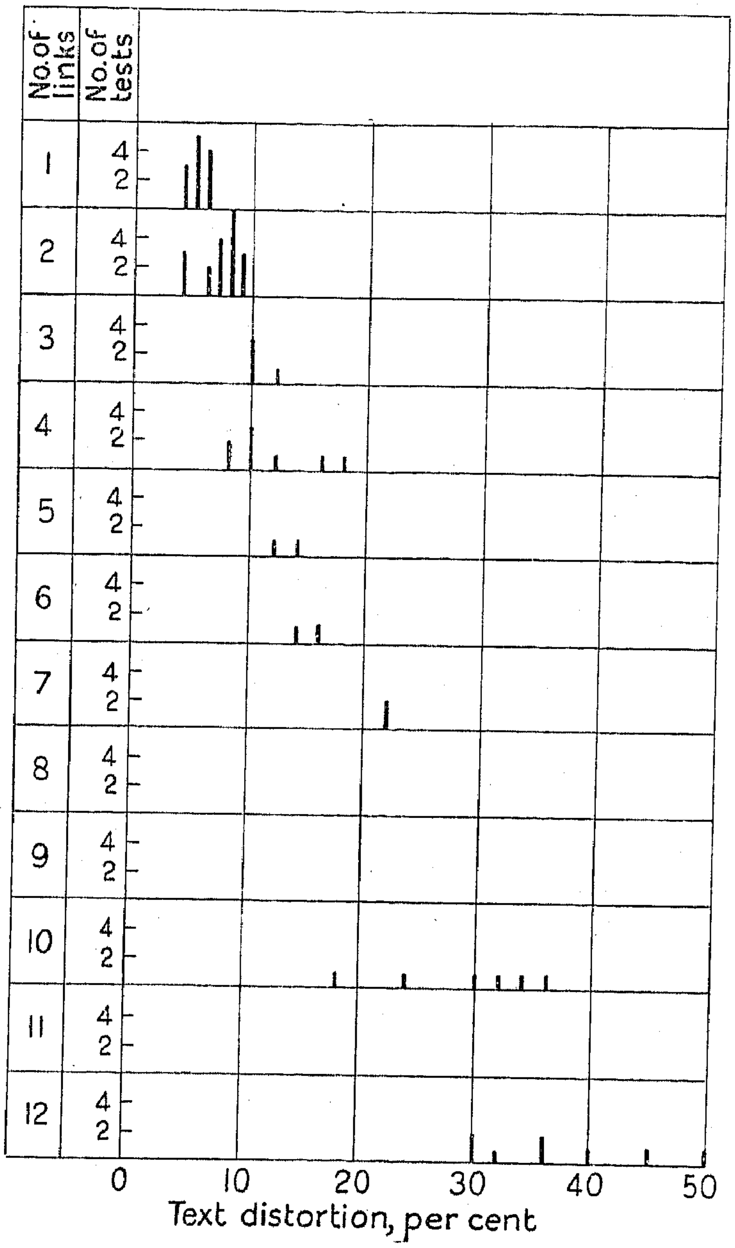

Fig. 8.—Effect on overall distortion of linking voice-frequency channels. Speed: 30 bauds.
Height of pillar represents number of tests made.

This apparent discrepancy in the case of particular channels is of importance only in relation to the design and adjustment of systems. Design and adjustment having once been standardized, it is the number that can safely or economically be linked together at random that is important.

The acceptance tests of the equipment demand that the maximum distortion at 66 bauds and with a ± 7·5-db variation in the level of the 4-wire circuit shall not be more than 25 per cent on any of the following signals: reversals, half-speed reversals, signals in the ratio of 1 to 5, and "Paris" in morse; the last two tests being repeated with the transmitting battery reversed. In practice the "Paris" and "Paris" inverted signals are found to be the best criterion of the channel from the point of view of teleprinter working, and as experience has shown that the 4-wire circuit level variations never approach the acceptance test figures it will be seen that these tests are essentially tests to prove and maintain the quality of new installations and have to be interpreted to gauge the performance of the equipment under practical conditions. It has been found that equipments conforming to the acceptance tests invariably give a satisfactory practical performance and are consistent one with another.

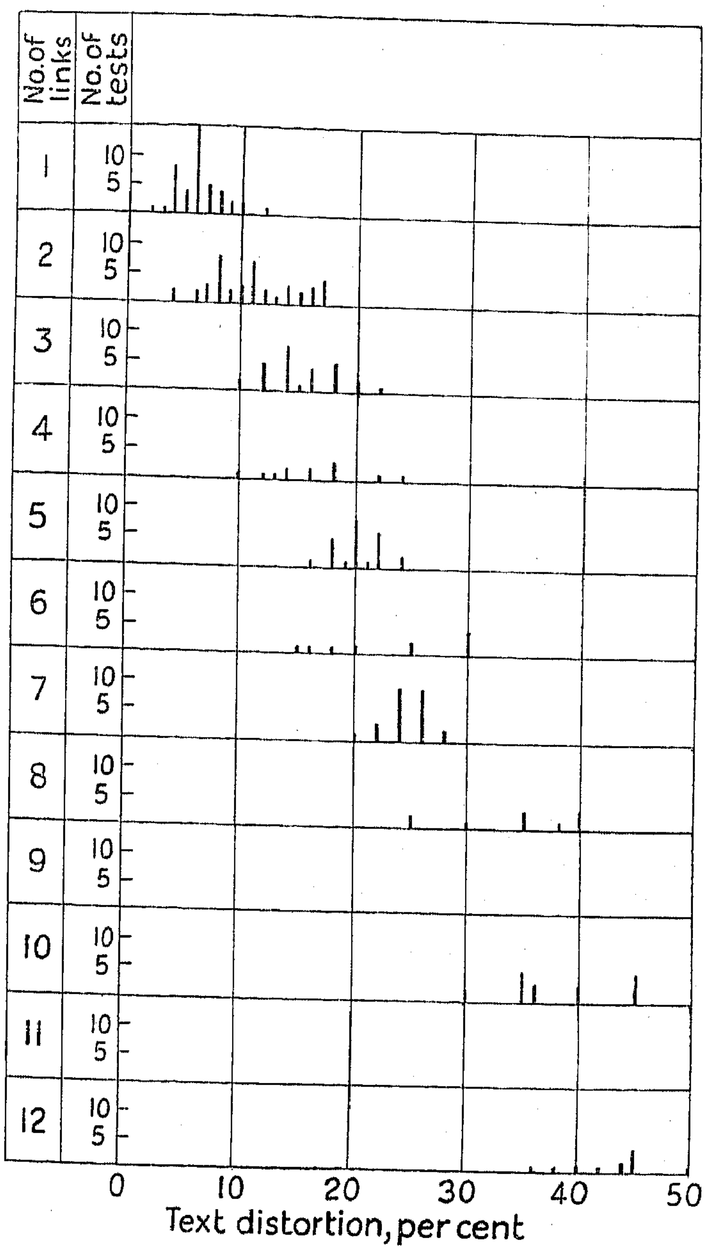

Fig. 9.—Effect on overall distortion of linking voice-frequency channels. Speed: 50 bauds.
Height of pillar represents number of tests made.

The approximate additive nature of average overall distortion on linked channels is shown in Figs. 8 to 11 for speeds of 30, 50, 66, and 80 bauds, respectively. The height of the pillars in these diagrams represents the number of separate tests made of the overall distortion, using the word "Paris" as the test text. The channels tested were taken at random over a long period by various observers from many different 12- and 18-channel systems under normal working conditions of line and apparatus.

In practice, 100 words per minute Wheatstone is regarded as the maximum commercial speed for a single-channel circuit. This figure allows a margin for contingencies and is reduced to 90 words per minute for two linked channels. Many such circuits are operated by private companies and are giving satisfactory service at these speeds, the performance being in agreement with the distortion test results of Fig. 11 (80 bauds).

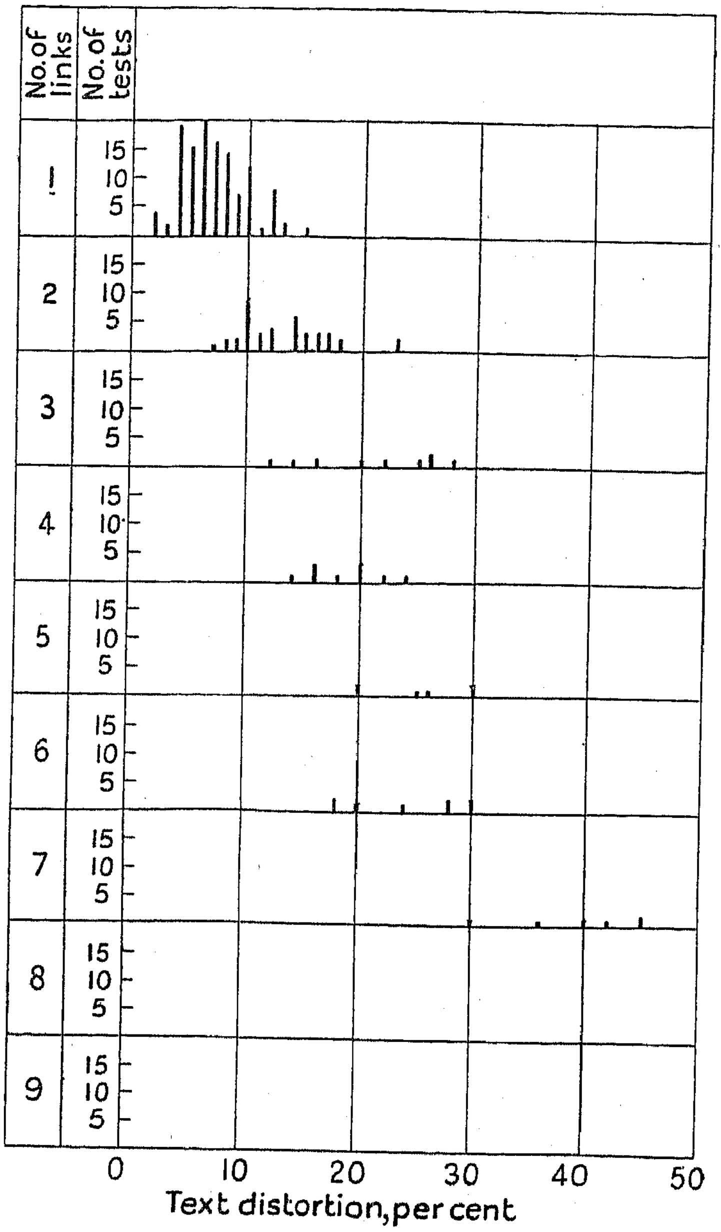

Fig. 10.—Effect on overall distortion of linking voice-frequency channels. Speed: 66 bauds.
Height of pillar represents number of tests made.

In order to determine the limits of channel linking for teleprinter working with *normal* conditions of channels and of teleprinters much experience and exhaustive tests are necessary. Brief tests made under good conditions may give extraordinary results such as good "songs" with 12 or more links, but exhaustive tests with all combinations of signals, fast keyboard operation, and allowable teleprinter-motor speed-differences, indicate that such results are not consistent enough to be commercial.

It has been found by both engineering and traffic tests that, taking channels at random and machines at random, seven channels may invariably be linked and produce satisfactory results. Even so, there are other considerations which must be taken into account in providing circuits with an appreciable number of linked channels. The network of the British Isles is almost completely triangulated, i.e. under cable-breakdown or other emergency conditions, for example, London–Leeds circuits can be provided via Edinburgh or Birmingham or Manchester, etc., by coupling the direct-current extensions from the channels at the voice-frequency control boards in the instrument rooms. Margin must, therefore, be left on all circuits to allow for the extra channels involved in such re-routing. Again, there must be a direct connection between the margin of circuits and the maintenance required by machines, and, although this aspect is becoming less important as the improved testing facilities for speed and margin of teleprinters are introduced, it still requires consideration.

There is also the question of economy; a multi-link circuit costs in respect of interest and depreciation of capital and maintenance of terminal apparatus an amount which is proportional to the number of links, and with flat-rate traffic charges this is clearly an important consideration.

Further multi-link circuits become cumbersome to handle and must unavoidably suffer stoppages in proportion to the number of links thus suffering, in comparison with 1- or 2-link circuits. It is well known also how the delay in rectifying any trouble seems to increase in much more than simple proportion to the number of people concerned in that trouble.

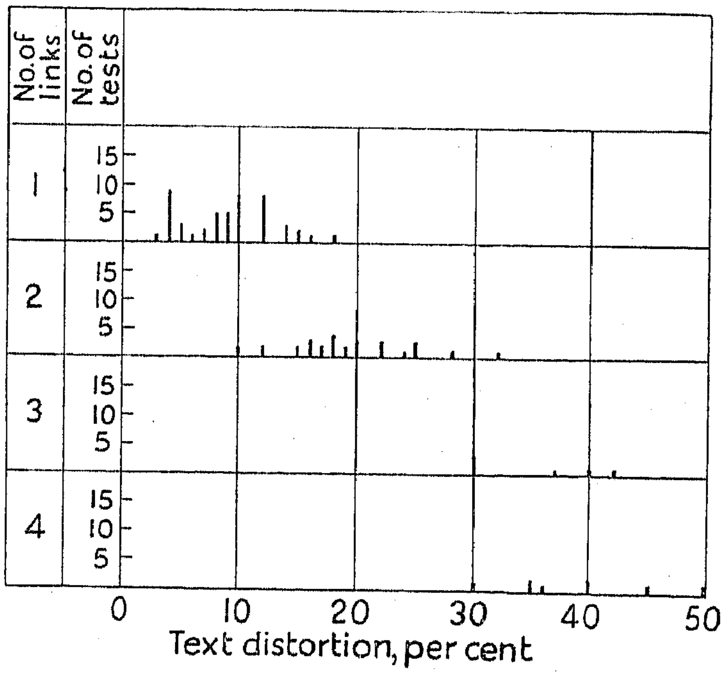

Fig. 11.—Effect on overall distortion of linking voice-frequency channels. Speed: 80 bauds.
Height of pillar represents number of tests made.

In the present network the majority of circuits are single-channel circuits, but there are a large number of 2-channel circuits and a few made up of three channels giving perfectly satisfactory service. There would be no objections in particular cases to using four links, but the general objections to such a number becoming common are those just mentioned. It must be pointed out, however, that different standards would exist in the case of international circuits, where a flat message-charge rate would not apply. In this case suitable maintenance could be justified economically to ensure that good commercial circuits without regeneration could be made up of five or six links, and also the apparatus costs would be relatively unimportant.

(g) Effect of Line Length on Distortion in a Multi-channel System

Tests have been made to examine the effect of the attenuation, phase, and non-linear distortion in long telephone lines on the telegraph distortion of a multi-channel system. The diagram in Fig. 12 and the results averaged in Table 2* show the telegraph distortion measured on a system working over distances of 0 to 1 100 miles; the last case involving 24 repeaters. It will be seen that in practice the effect of the number of repeaters and length of line is negligible.

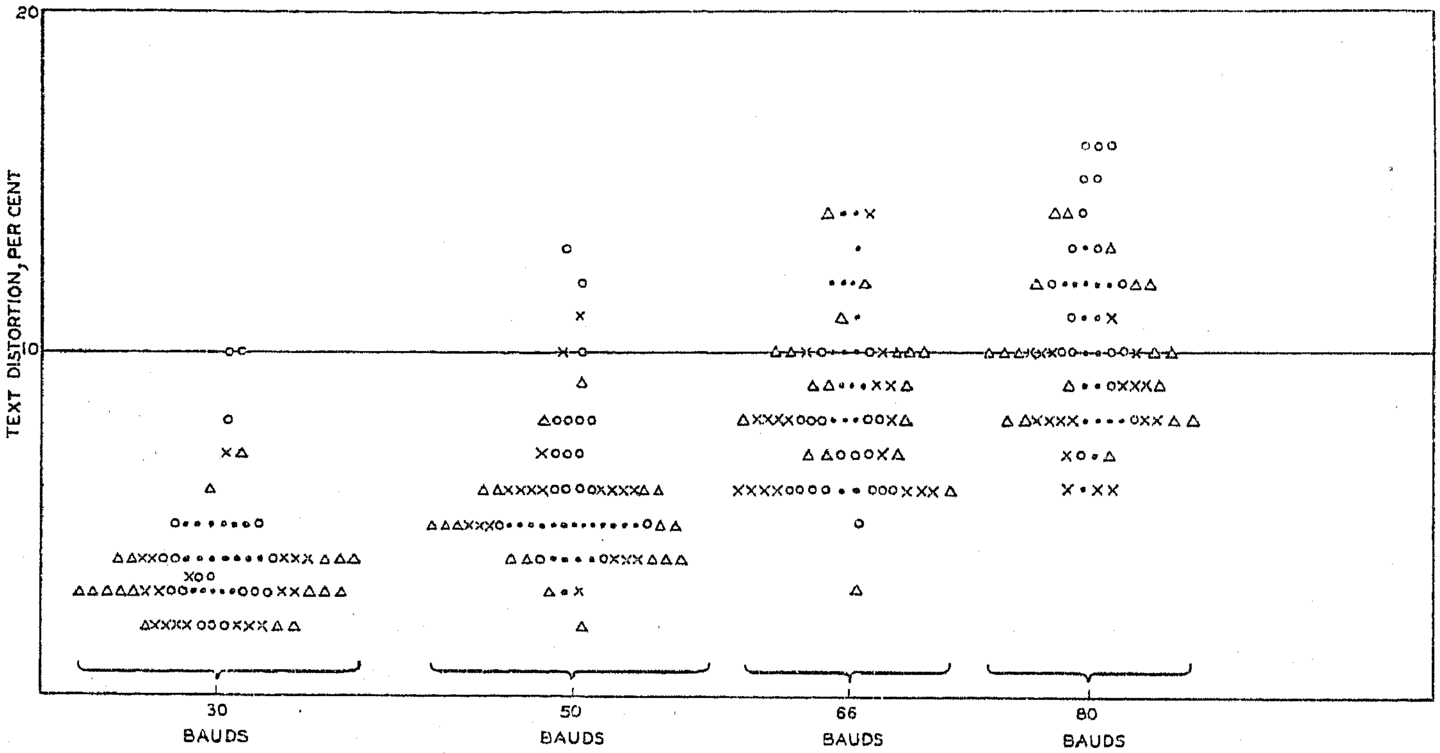

Fig. 12.—Effect of 4-wire circuit length on distortion at 30, 50, 66, and 80 bauds. Nine channels tested in each case, with " Paris " and " Paris " inverted.

Dots refer to TS—BM—TS—DE—TS circuit, 1 100 miles.
Circles refer to TS—DE—TS circuit, 900 miles.
Crosses refer to TS—BM—TS circuit, 200 miles.
Triangles refer to 0 miles.

Table 2

		Length of circuit (miles)			
		0	200	900	1 100
Speed (bauds)	30	3·5	3·1	4·3	4·1
	50	5·1	5·8	7·2	4·7
	66	8·9	7·8	6·6	10·0
	80	10·2	8·4	12·0	9·9

(h) Valve Receiving Relays and Static Modulators

In the multi-channel equipment the amplifier-rectifier operates a telegraph-type relay which is associated with the voice-frequency equipment and works the telegraph receiving apparatus over d.c. extensions.

Consideration has been given from time to time to the possibility of replacing the receiving relays by valve relays. While, however, suitable valve relays for particular purposes have been developed* and give complete satisfaction for those purposes, a satisfactory economic general alternative to the electromagnetic relay is not available. Apart from 3-monthly routine cleaning and adjustment, receiving relays only require attention on an average once in 40 weeks, and it is doubtful whether a valve relay panel fulfilling the requirements would require less maintenance. The introduction of copper-palladium for contacts instead of platinum-iridium resulted in a large decrease in receiving-relay maintenance owing to the elimination of the tendency of platinum to weld and build up points on the contact surface. The introduction of series resistance into the leads to the teleprinter also gave a marked improvement from this point of view, by limiting the discharge of the condensers associated with the teleprinter electromagnet and the normal shunted condenser.

Contrary to the case of receiving relays, it has been definitely established that platinum or platinum-iridium contacts are much superior to copper-palladium for voice-frequency transmitting relays. In this case the contacts are called on to short-circuit the voice-frequency current at a point where the potential is a small fraction of a volt. Trouble which is well known to be associated with such conditions shows itself occasionally, particularly on high-speed circuits, where the incomplete suppression of the carrier in the spacing elements, due to high contact resistance, is liable to cause biased signals.

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* The average distortion (per cent) of 9 channels is given in each case.

* See Bibliography, (41) and (42).

The principle of using a non-linear conductor as a variable a.c. impedance by polarizing it with direct current, has of recent years received considerable attention owing to the availability of small copper-oxide rectifiers, which make almost ideal elements for the purpose. Various ingenious circuit arrangements have been devised in connection with telephone transmission,* and in voice-frequency telegraphy similar principles can be used to modulate the outgoing voice-frequency currents instead of using electromagnetic relays. Such modulations, when controlled by square d.c. signals, produce an instantaneous change in the amplitude of the carrier, but, by arranging that the a.c. output is proportional to the d.c. input, the modulator in conjunction with a low-pass filter can be made to replace the sending relay and the associated band-pass sending filter in a multi-channel system. Sending filters are eliminated by this means in some systems in use on the Continent† and also in the London–Leafield radio keying system, designed by the Post Office for keying radio transmitters at Leafield over landlines from London. This system, which also incorporates valve trigger relays at the receiving end, has proved advantageous and reliable since its installation in 1933.‡ On the multi-channel voice-frequency network, experience has proved that static modulators are preferable in every way to electromagnetic transmitting relays, and increased stability and decreased maintenance costs have resulted from their use. The question of elimination of the sending filters is of less importance, as the saving involved is solely in first cost and is offset by the increased dependence on adjustment of the current conditions on the incoming physical extensions.

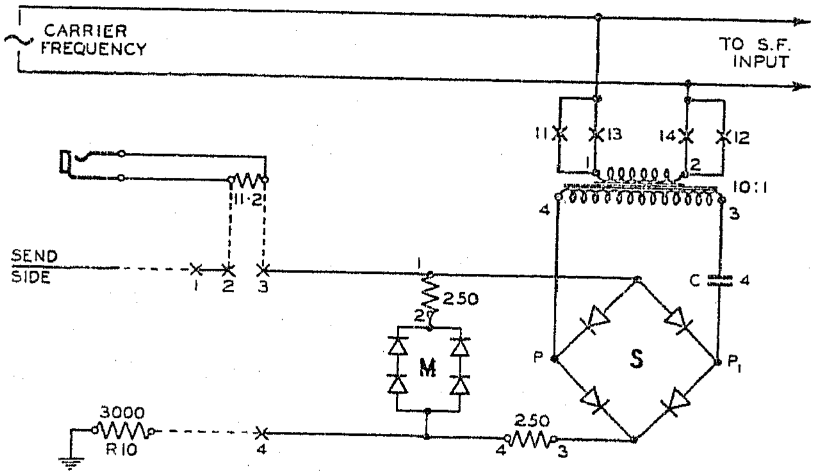

Fig. 13.—Schematic diagram of static relay.
X = Jack connections to relay base.

In the voice-frequency network, static modulators are being increasingly used, the particular arrangement being shown in Fig. 13. This type has been designed to be interchangeable, both mechanically and electrically, with the ordinary electromagnetic relay, so that it can be introduced on channels of existing equipment as and when convenient. Apart from the increased stability provided, these modulators give distortion figures which are slightly better with normal or high line levels, and considerably better with low line levels, than those obtained using good relays. This is due to the effect of the transit time of the transmitting contacts and to the effect of the quench condensers not being the same in the two cases, and the consequent effects on the biasing circuits of the receiving equipment. The spacing level of the tone sent out is about 34 db below the marking level, a figure obtained by using a very high-quality transformer. The controlling current required may be from 4 mA or less up to 20 mA, which is the maximum figure obtainable on the shortest extension.

In practice an important advantage of static modulation is that in addition to the elimination of send-relay faults (which preponderate in the ratio of 2 or 3 to 1 as compared with receiving-relay faults) no time is lost, when fault-localizing is being carried out, in deciding at which of the two ends of the circuit the relay requires adjustment.

(j) Four-channel Duplex System for Minor Routes

A 4-channel duplex system for extending the voice-frequency network to minor routes which may not justify the provision of a 12- or 18-channel system has been introduced.* This equipment operates on repeatered or non-repeatered 2-wire circuits having an attenuation up to 18 db. Each channel transmits to line at 100 microwatts. The frequency-spacing is 240 cycles, the actual frequencies being 420, 660, 900, and 1 140 cycles per sec. in the one direction and 1 380, 1 620, 1 860, and 2 100 cycles per sec. in the other. The increased spacing allows filters similar to the sending filters of the main-line equipment to be used for both sending and receiving. The equipments are made for either battery or all-mains supply, and the performance of the channels is identical with that of the main-line equipment.

(k) Super-audio (Supra-acoustic) Systems

The a.c. telegraph systems previously described operate on carrier frequencies lower than about 2 500 cycles per sec. and use the telephone channel to the exclusion of other services. There are in existence, however, telephone channels having a pass range extending above the highest frequency necessary for the commercial transmission of speech (2 400 cycles per sec.), which can accommodate one or more telegraph channels, known as super-audio channels, in the unused portion of the range. Examples of this type of circuit are the extra light-loaded circuits (44 mH at 1·136 miles), having a cut-off frequency of 5 500 cycles per sec. and a useful pass range up to 4 300 cycles per sec., which were designed primarily for high transmission velocity, and unloaded or continuously loaded submarine cables, not equipped with carrier telephone apparatus. The extra light-loaded circuits referred to are unsuitable for music transmission or carrier telephone working, but can easily accommodate one or more carrier telegraph channels. It is immaterial whether the range below 3 000 cycles is used for speech or for multi-channel telegraphs.

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* See Bibliography, (39) and (40). † *Ibid.*, (15). ‡ *Ibid.*, (18).

* See Bibliography, (19).

There are two principal methods of providing super-audio telegraph channels:—

(i) That in which the carrier frequencies are modulated by the telegraph transmitter in the same manner as is employed in the lower-frequency channels.*

In this case the carrier frequencies are generated by means of oscillators, and the operation is in principle the same as in voice-frequency systems. It is usual to employ a greater frequency-spacing between adjacent channels, chiefly because of the greater percentage accuracy required in the separating filters. In addition to the usual sending and receiving filters required where more than one super-audio channel is provided, master filters separating the audio telephone channel and the super-audio telegraph channels must also be installed.

An example of this type of super-audio system is to be found in the Anglo-Dutch submarine cable, on which a teleprinter circuit has been operating on this basis since December, 1933. The installation of a second circuit is in hand, and ultimately six or more duplex channels are envisaged.

(ii) That in which the principle of double modulation is employed.

The principle of double modulation is well known in carrier telephony and it can be applied also to telegraphy.† In practice this is carried out by employing a carrier telephone channel to carry the modulated carriers of a voice-frequency multi-channel system. Only one side-band, the lower, is transmitted, and thus the high-frequency channels of the voice-frequency system become the low-frequency channels of the super-audio system. The standard carrier frequency for carrier telephony in this country is 6 000 cycles per sec., and therefore the frequencies of the super-audio channels become 3 540 cycles, 3 660 cycles, etc. It will be noticed that the principle of employing the odd multiples of 60 cycles per sec. as carrier frequencies is preserved.

There are obvious advantages in this method of working. The same type of terminal equipment is employed on both audio-frequency and carrier circuits, and setting-up and maintenance does not differ from normal practice. Further, the channel frequencies can be obtained from the existing multi-frequency generators, and difficulties in the design of filters for high frequencies are avoided. This method necessitates, however, a high degree of equality between the frequencies of the oscillators in the modulating and demodulating equipment. This is obtainable by means of temperature-compensated coils or by thermostatic control. An experimental 8-channel system has been installed on this basis between London and Newcastle. If experience with this system is satisfactory it is probable that considerable use will be made of it for the economic provision of channels for all purposes.

In both systems of super-audio operation it is assumed that the telephone repeaters *en route* will deal with both speech and telegraphs, and to minimize the effects of cross modulation it is essential that the peaks of speech be limited to prevent overloading. Special monitoring arrangements at the repeater stations may also be necessary to prevent interference with the telegraph channels.

(4) TECHNICAL CONSIDERATIONS RELATING TO ALTERNATING-CURRENT TRANSMISSION

(a) Line Characteristics

Normally, a.c. or carrier telegraphy consists of modulating a carrier wave in accordance with the movements of a telegraph transmitter, the whole or part of the available frequency-band width of normal telephone circuits being used for the transmission path. The sources of distortion in an a.c. transmission line are well known, but the most important affecting carrier telegraphy are given below.

(i) Restriction of transmission frequency band.

The effect of restricting the transmission frequency band is to delay the rise in the amplitude of the carrier, and the building-up time from the first appearance of the signal to the steady-state amplitude is equal to $1/(f_2 - f_1)$, where f_2 and f_1 are respectively the higher and lower cut-off frequencies.* In the practical case this is only approximately true, as it is impossible either to define the actual cut-off frequencies or to determine exactly the building-up period. Nevertheless, the simple formula will enable apparatus to be designed according to the telegraph speed required of the channel, provided due allowance is made for the imperfections of filtering equipment. Thus Figs. 14 and 15 respectively show the attenuation/frequency curve of a typical voice-frequency channel and the envelope of the voice-frequency signal. The calculated cut-off frequencies differ by 120 cycles per sec., but the available band width will be seen to be roughly 70 cycles, which agrees fairly closely with the measured building-up time (14 milliseconds) of the carrier, as shown in the oscillogram.

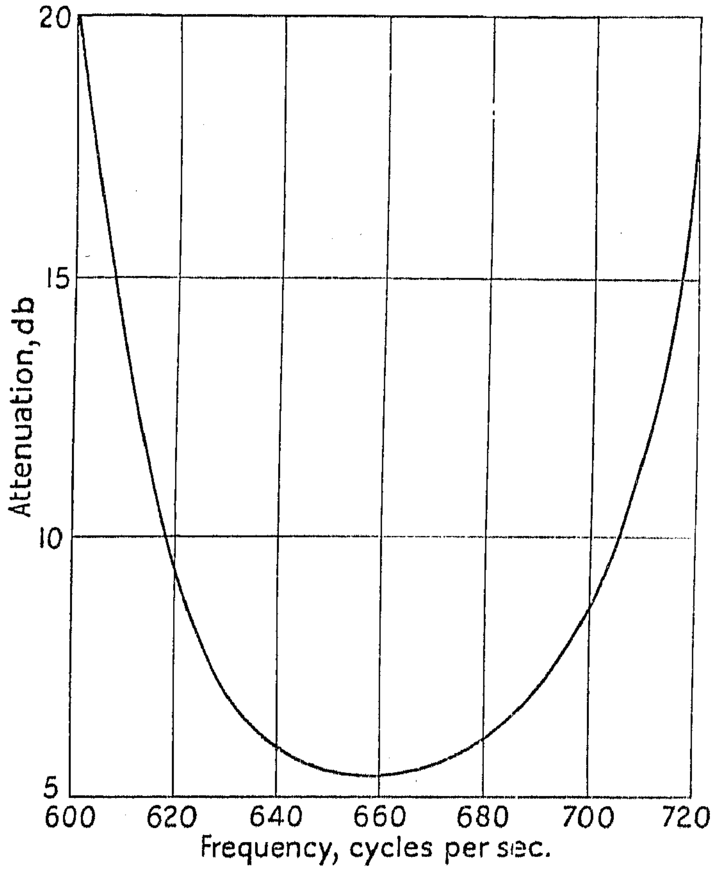

Fig. 14.—Attenuation of voice-frequency channel.

It is evident that, with simple means of rectification, the maximum speed of a channel without appreciable telegraph distortion is equal in bauds to the available frequency-band width of the channel. It is also evident that in a.c. telegraphy the frequency band width required for a given telegraph speed is twice that required in d.c. telegraphy, where the carrier frequency may be regarded as zero and the upper and lower side-bands coincident.

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* See Bibliography, (24), (25), and (26).

† *Ibid.*, (23).

* See Bibliography, (9).

(ii) Phase distortion.

The general effects of phase distortion in delaying the building-up of an a.c. signal are well known. The influence of phase distortion on telegraphic distortion depends very largely on the action of the detector in the subsequent restoration of the d.c. character of the signal, but, in any case, the effects of delay in the build-up of the signal are the same whether it is produced by phase distortion or by restriction of the transmission band. More information on this point is given later in the paper when the action of the receiver is discussed.

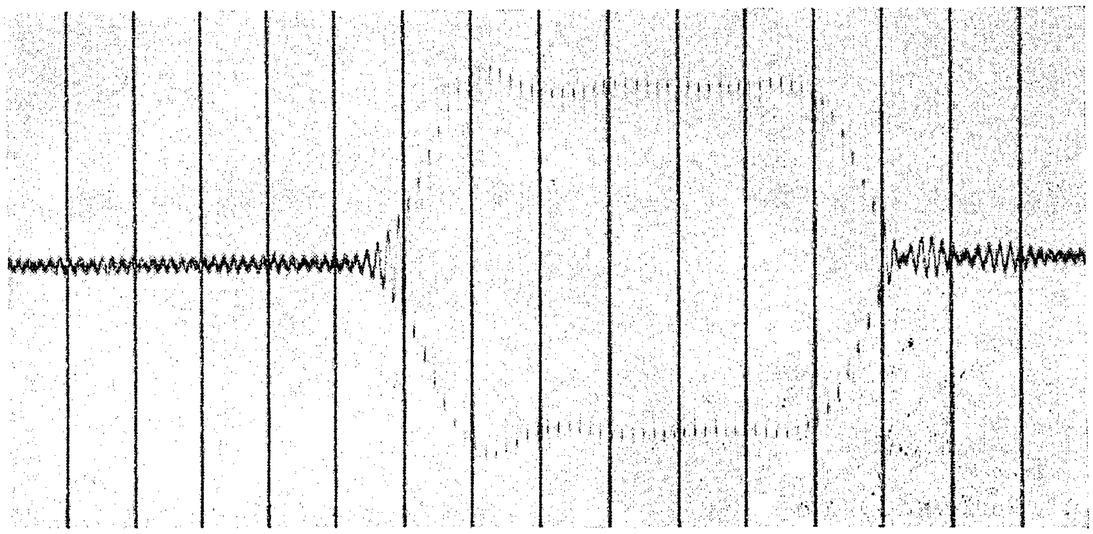

Fig. 15.—Effect of restricted transmission band on envelope of a voice-frequency signal.
10-millisecond timing lines.

The electrical networks commonly employed in telephone transmission lines for phase correction are necessary on telegraph circuits only where transmission of a broad frequency band is required, such as in picture transmission. In the more usual type of telegraph transmission, the difference in delay time over the essential transmission band width renders the use of special phase-correctors unnecessary provided the band is suitably restricted by means of filters. In multi-channel systems the filters must be provided to separate the channels; and in single-channel systems, although sending and receiving filters are not strictly required, they may be inserted where excessive phase distortion is present. The building-up time of a signal is then dependent on the width of the transmission band, and the effect of phase distortion is negligible except where the rate of change of the phase constant with respect to frequency is changing very rapidly.*

(iii) Non-uniformity of attenuation over the transmission band.

The effect of non-uniformity of attenuation over the transmission band is similar to that of phase distortion in that it delays the building-up and dying-away of the carrier. This is not a condition which occurs frequently in modern telephone circuits, as all main-line repeaters are equipped with attenuation equalizers.

Over the transmission band of any one channel in a multi-channel system, the maximum difference in attenuation is not more than 0·5 db even for the lowest frequency channel, and is therefore negligible; but the overall difference between frequencies in different channels leads to a reduction of the signal/interference ratio and must therefore be taken into account.

Again, in single-channel systems the effect is limited by a receiving filter if one is employed, and obviously, where a wide transmission band is required, uniformity in attenuation can only be secured by careful adjustment of equalizers.

(iv) Non-linear distortion.

Non-linear distortion in thermionic valves and loading coils and transformers, resulting in the production of second and third harmonics of the carrier frequency, is also present in telephone lines. With the normal type of equipment, effects due to this cause are inappreciable, although it might be anticipated that in the multi-channel case production of third harmonics of (say) the first channel carrier (420 cycles per sec.) would interfere with the operation of the eighth channel (1 260 cycles per sec.). The production of even harmonics due to non-linearity of valve characteristics is undoubtedly more serious, but as the carrier frequencies have been selected so that the resulting harmonics fall midway between channels, their effect is greatly reduced.

(b) Effect of Variations in Receiving Level

Alternating-current transmission, utilizing one carrier per channel, is equivalent to a single-current system, and the receiving relay requires a bias—either electrical or mechanical—to return the armature on the cessation of the signal; and as the restoring force is fixed, once the channel has been set up, variations in the level of the received signal produce bias distortion. It is essential, therefore, that means of overcoming the effect of variations in attenuation should be introduced; and it will be found that differences in the various designs of a.c.

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* See Bibliography, (8).

telegraph receivers are largely due to the differences in the manner in which this problem is tackled.*

As in the case of single-current d.c. telegraphy, the importance of maintaining a definite signal amplitude is dependent on the shape of the signal envelope. That is, where the signal envelope is rectangular in form, the distortion introduced by a given change of amplitude is considerably less than where the wave-form rises slowly. It is necessary, in the former case, that the signal amplitude should be considerably more than the minimum operating current of the receiving relay, and also that the change of flux in the relay core should be similar in form to the change of potential of the received signal. The latter is very rarely the case, owing to the impedance of the relay being variable with frequency and also owing to the production of eddy currents in the relay core which delay the change of effective flux. Further, in the case of carrier telegraphy, it is necessary to smooth the demodulated signal by means of a low-pass filter, which delays the rise of current in the relay winding and therefore the change of flux in the relay. In the majority of modern telegraph systems the speed of working in relation to the available frequency band is such that the a.c. signal reaches the steady-state condition immediately prior to the cessation of the signal, and the effect of variation in the signal level is evidently serious.

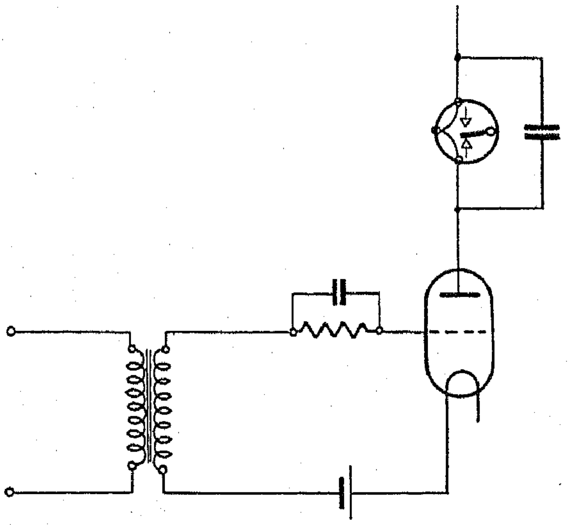

Fig. 16.—Simple grid limiter.

The magnitude of the variation to be expected in the level of the received signal depends on the system to be employed. Multi-channel systems which are set up permanently on a particular circuit are designed to operate over a maximum range of 15 db, whereas the equipment employed on the telex service must deal with signals varying in level by at least 30 db. The effect of line-attenuation changes depends on the speed of transmission and the building-up period of the signal envelope. Thus, with building-up and dying-away periods of 14 milliseconds and a transmission speed of 50 bauds, the maximum distortion for 15-db change of level, if simple forms of rectifier and relay receivers are employed, is about 35 per cent.

(c) Design of A.C. Telegraph Receivers

To compensate for the effects of long building-up and dying-away periods and variations in the level of the received signal, all a.c. telegraph receivers employ some form of limiter. The commonest type of limiter depends for its operation on the change of grid-cathode impedance of a thermionic valve when the potential of the grid reaches the point where grid-cathode current commences to flow, and also on the rectifying property of the grid-cathode circuit. In its simplest form the grid limiter is shown in Fig. 16. The normal relative potentials of the grid and cathode depend on whether the valve is being used as a rectifier or an amplifier, but the limiting property is not affected by this.

A signal of large amplitude applied to a receiver of this type operates the receiving relay at the beginning of the building-up period of the envelope; and, when the peak amplitude exceeds the normal grid bias, grid-cathode current flows and charges the grid condenser. Thereafter, only the peaks of the half-waves produce grid current and only the top part of the signal produces anode current. If the time-constant of the condenser and resistance is great compared with the time between successive half-waves, the effective portion of the signal is at the top of the envelope, and, if the amplitude of the signal is reduced, the signal in the anode circuit ceases as soon as the amplitude of the a.c. signal on the grid falls below the additional grid bias built up on the grid condenser.

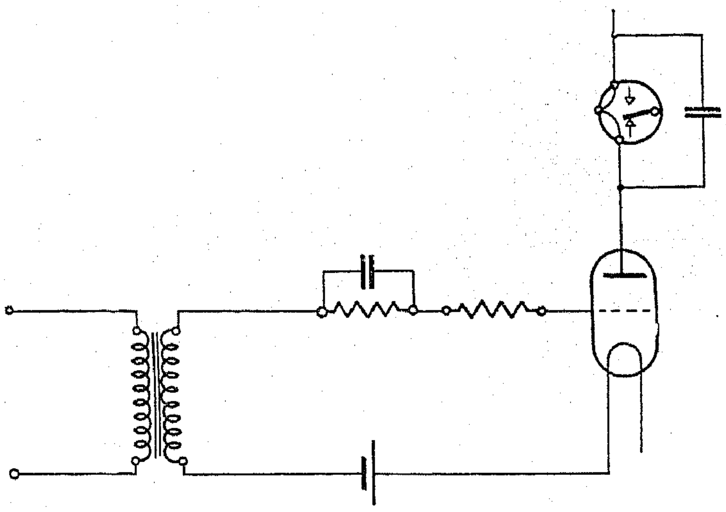

Fig. 17.—Grid limiter with unshunted resistance.

As the operating point on the cessation of tone is dependent upon the biasing voltage produced by the flow of grid current, it is possible to control the position of this point by controlling the biasing voltage developed. Where the sending impedance is of the same order as the grid-cathode impedance, the grid condenser is quickly charged, and therefore the biasing voltage approximates to the peak voltage of the applied signal; and conversely if the sending impedance is high the condenser is charged to only a small fraction of the signal peak-voltage. Thus the operating point of the relay can be controlled by adjustment of the sending impedance, and this is most conveniently done by including in the grid circuit a resistance not shunted by the condenser, as shown in Fig. 17.

During the quiescent period between signals the condenser discharges through the shunting resistance, and therefore the time-constant of the circuit influences the relay operating point on the envelope of the next signal received. Thus, if the time-constant is high compared with the length of the quiescent period, the third operation occurs at approximately the same amplitude as the second; and if the time-constant is low, the third operation occurs at the same amplitude as the first. The relay-operating points of the envelope can therefore be controlled by adjustment of the values of the components in the grid circuit, the optimum values being dependent upon the conditions of working of the system.

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* See Bibliography, (14) and (16).

Where it is possible to arrange for tone to be transmitted in the idle periods, the longest period of no tone is equivalent to 5 elements, and a receiver having a large time-constant gives the best operating conditions. In this case, all operating points occur at approximately the same amplitude, which may be arranged to be equal to half the peak amplitude. If all operations occur at half the peak amplitude there can be no telegraph distortion, but in practice this is not possible because the additional bias built up by the signal must fall slightly during the no-tone periods and also because the building-up of the charge is not instantaneous. It is possible, however, to reduce the 35 per cent distortion, previously mentioned, to about 12 per cent.

In cases where it is not possible to transmit tone in the idle condition, the M-to-S (mark to space) operating point after a period of rest is always at the beginning of the building-up period of the signal. The best S-to-M operating point is therefore at the beginning of the dying-away period, and, with a hang-over time shorter than the shortest tone-off period, the next M-to-S operation would be at the beginning of the next build-up. No telegraph distortion would be introduced, but in practice it is found that the time-constant cannot be reduced to the required value because the rate of die-away of the condenser voltage must be less than that of the signal, and therefore there is some distortion of the second and subsequent M-to-S operations. This can be reduced by arranging that S-to-M operations occur later in the die-away, in which case the total distortion is divided between the M-to-S and S-to-M operations. The maximum distortion is reduced in this way, but it is evident that in the extreme case, where the first M-to-S operation occurs at the commencement of the building-up period and all subsequent operations occur at half the peak amplitude, the maximum distortion measured as a time-interval approaches half the build-up time of the signal envelope. This arrangement is employed in the equipment used in the Post Office telex system. It is interesting to note that when component values are adjusted so that all operating points after the first occur at half the peak amplitude, the average current in the anode circuit is constant over a wide range of signal level, and this fact may be used as an indication that the required conditions have been obtained. In this particular equipment, the extra resistance in the grid circuit is unnecessary owing to the high step-up ratio of the input transformer. In order to utilize the mid-portion of the signal envelope the effective grid bias should obviously be equal to half the peak voltage of the signal plus half the effective grid swing, and that portion of the grid bias due to the charge on the condenser should be equal to half the peak voltage minus half the effective grid swing. The curves given in Fig. 18 therefore show the average direct current in the anode circuit, the actual voltage produced across the grid condenser, and the calculated half peak voltage. It will be seen that there is very close agreement between the calculated and measured voltages.

In the multi-channel system used in this country the correction is made partly in the rectifying valve and partly in a preceding valve amplifier. In this system the flow of grid current in the rectifier and the consequent charge on the grid condenser, bias both the rectifier and the amplifier. The result is that the rise of current in the rectifier anode circuit is delayed owing to the reduced amplifier gain, and it is arranged that the anode current in the rectifying valve reaches a predetermined value, at which the receiving relay operates, when the signal applied to the amplifier reaches half the peak amplitude. The return operation of the relay takes place at approximately the same point of the envelope.

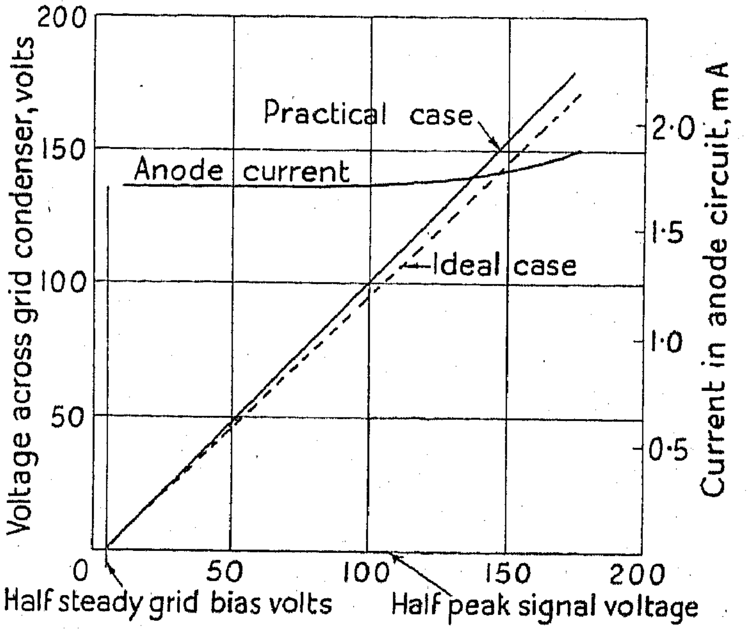

Fig. 18.—Relation between peak signal voltage and voltage developed across grid condenser.

(i) Effect of half-wave rectification on receiver distortion.

The receiving circuits described employ half-wave rectification, and the phase of the carrier at the instant of modulation has some influence on the time-interval between the operations of the transmitting and receiving relays.

In the worst case, where the length of the signal is equal to an odd multiple of one half-cycle, the effective length of the rectified but unsmoothed signal may vary by the length of one complete cycle, and therefore the maximum possible distortion in milliseconds is equal to 1 000/*f*, where *f* is the carrier frequency.

In practice, the low-pass filter, which retards the change of current in the receiving-relay winding, and the bias-current adjustment, modify this result. The maximum difference of the time-intervals between the operations of the transmitting and receiving relays is equal to one half-cycle, at both the beginning and the end of a signal; but, by adjustment of the bias current, the mean interval between the operation of the transmitting relay and the corresponding operation of the receiving relay, for the commencement of a signal, is made equal to that for the end of a signal. The maximum difference of time-interval corresponding to the two operations is then equal to one half-cycle, i.e. 1 000/(2*f*) milliseconds, and the distortion is equal to 100*N*/(2*f*), where N = telegraph speed in bauds.

With full-wave rectification, which has been employed in experimental receivers constructed in the Research Laboratories of the British Post Office, the distortion is reduced to one-sixth of a complete cycle, i.e. 1 000/(6*f*) milliseconds.

(ii) Direct operation of machine telegraph receivers from thermionic valves.

Where direct operation of machine telegraph receivers is required, further amplification of the limited signal will usually be necessary and this may be provided in a variety of ways.

First, further valves are employed as amplifier of the d.c. component or as rectifier and amplifier of the a.c. component, with the operating winding of the receiving magnet in the anode circuit. Some types of voice-frequency equipment for telex operate on this principle.

Second, the limiting valve is followed by dry metal rectifiers, and further valves are employed as a d.c. amplifier.

Third, the limiting valve operates as a rectifier, and the transients obtained on build-up and die-away are amplified by means of a push-pull amplifier and operate the receiving magnet on a double-current basis. This is the system employed at present on the voice-frequency equipment for telex in this country.

(iii) Operation of sensitive relays.

The usual method of operating relays in carrier-current telegraphy is directly in series with the anode of the limiting valve.

As the carrier operation is effectively single-current, the receiving relay requires either mechanical (spring) or electrical bias to restore the armature on the cessation of the operating current. Owing to the high impedance of the relay winding at carrier frequencies a path for the a.c. component is required, and this usually takes the form of a condenser connected directly across the relay winding.

There is some slight advantage in using the anode supply for the bias current, as variations in the anode voltage produce similar variations in the operating and biasing circuits, and therefore tend to compensate one another. The compensation is, however, not completely effective.

Another method of operating the relay is in a bridge circuit, in which the valve forms one arm of the bridge.* A bias winding is, of course, unnecessary and a form of double-current operation is produced. It is well to remember, however, that the operation is, in effect, single-current, with electrical bias, and it possesses no particular advantage over the simple method discussed above.

(d) Transmission Problems peculiar to Telex Services

A diagram of the subscribers' apparatus used for the telex system is shown in Fig. 19.† The transmitter consists of a single-valve oscillator and the receiver of a rectifying valve which combines the functions of rectifier, limiter, and echo-suppressor, followed by a push-pull amplifier, which amplifies the transients obtained on the growth and die-away of the rectified voice-frequency signal sufficiently to operate the teleprinter without intermediate relays. The echo-suppressing feature is required to cater for short trunk circuits not equipped with the telephone-type echo-suppressors; and is obtained by increasing the time-constant of the grid resistance and condenser to cover that period wherein an echo may be received.

The effect of hang-over time in the grid resistance and condenser on distortion has been discussed previously, and in this particular case the resulting distortion may amount to half the building-up time of the signal. No filters are included in the equipment, and thus the delay in the building-up of the signal is due only to phase distortion in the circuit. The resulting telegraph distortion on the longest lines in this country is about 12½ per cent and, as the carrier frequency is low (300 cycles per sec.), the repeaters and line transformers account for practically the whole of this.

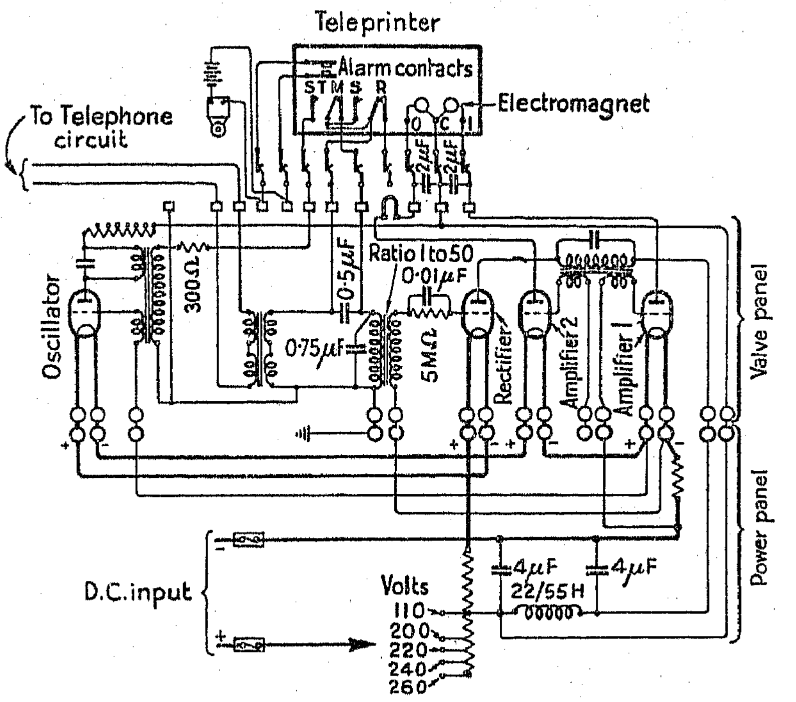

Fig. 19.—Diagram of subscriber's telex equipment (d.c. mains).

For international working, the carrier frequency of 300 cycles per sec. is considered to be too near the cut-off of many foreign circuits for satisfactory transmission; and, because phase distortion at low frequencies, being dependent on the number of repeaters, would become serious on long circuits, the question of using a higher frequency was examined. A frequency of 1 500 cycles per sec. has now been internationally agreed upon, and this frequency will also be used for the inland service.

The choice of a frequency higher than 300 cycles per sec. is restricted on account of the use of the band between 500 and 1 000 for signalling on the telephone circuit, together with the greater cross-talk at the higher frequencies. At frequencies between 1 000 and 1 200 cycles per sec. the degrading effect on articulation is particularly bad, owing to the sensitivity of telephone receivers at those frequencies. At 1 500 cycles per sec., however, it has been found that the sending level can be maintained at such a point that main-line repeaters can be fully loaded without causing an appreciable loss of articulation in an adjacent telephone circuit.

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* See Bibliography, (22).

† *Ibid.*, (21).

The operation of voice-frequency telegraphy on ordinary telephone lines with intercommunication facilities introduces special additional problems not experienced on point-to-point services. The most important of these, from an engineering standpoint, are the operation of echo-suppressors and the effect of line noise.

(i) Operation of echo-suppressors.

It is essential that the operation of echo-suppressors on trunk circuits should be sufficiently rapid to prevent the possibility of the passage of reflected currents. The time of operation necessary to prevent this will, of course, be dependent on the length and composition of the particular circuit and on the location of the echo-suppressor. The hang-over time must also be such as to allow of the reception of the " answer back " signal.*

The operating time of the hitherto standard echo-suppressor used in Great Britain is about 20 milliseconds, and provided that the transmission time from the echo-suppressor station to the receiving terminal and back is greater than this, no difficulty is experienced. Where the transmission time is less than this, it is possible for the reflected signal to operate the other half of the suppressor and tend to suppress the originating signal. Some trouble has been experienced on circuits having a short transmission time and it has been overcome by arranging that the suppressor, in addition to suppressing the return repeater, suppresses also the amplifier of that half of the suppressor which should not operate.

The hang-over time of the limiting circuit in the convertor has been increased to provide for echo-suppression for periods up to 50 milliseconds. It is therefore unnecessary for the beginning of a reflected signal to be fully suppressed. On short-circuits this is important, because too-rapid build-up of the suppressing voltage produces a surge on the line which may cause errors in the telex transmission and, in extreme cases, instability of the echo-suppressor and repeater.

The hang-over time is limited by the rapidity with which the " answer back " signal is transmitted. On the teleprinters used in Great Britain, a period of 160 milliseconds elapses before the " answer back " unit begins to transmit, and as it is unnecessary for the first letter-shift signal to be received a maximum hang-over time of 310 milliseconds is permissible. This figure should be increased by the transmission time of the circuit from the suppressor station to the receiving terminal and return, but in many cases this is negligible.

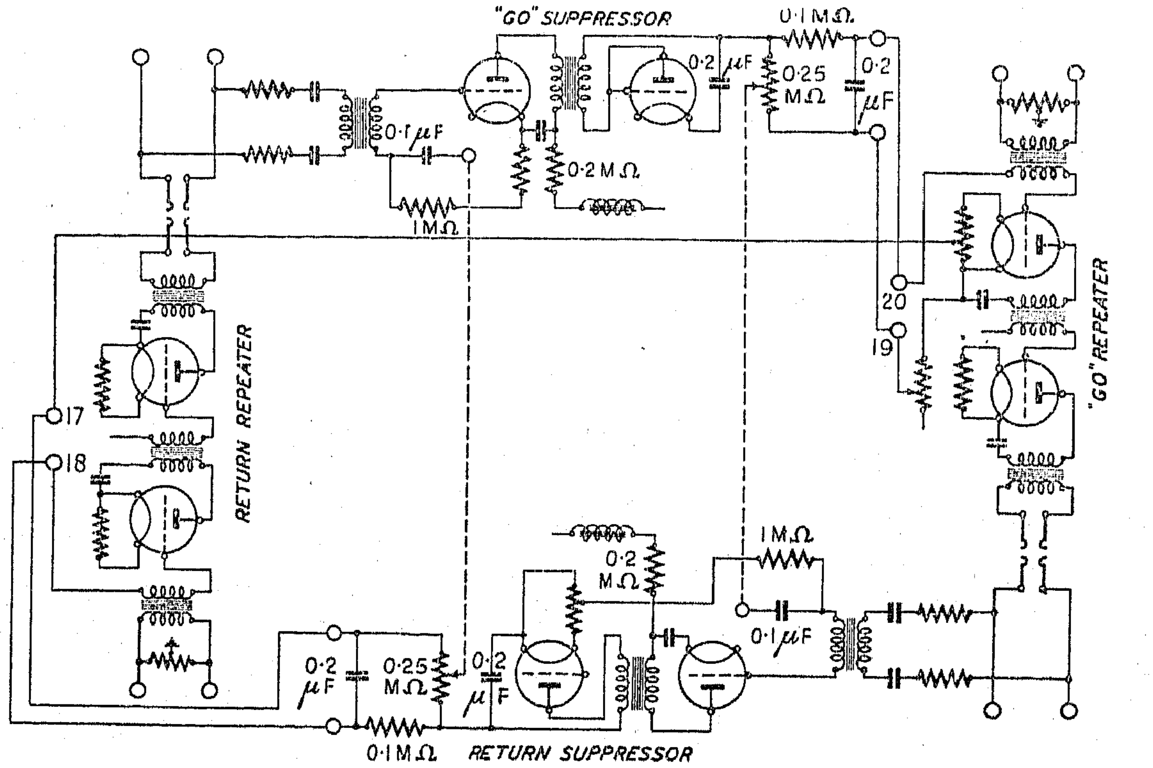

Fig. 20.—Typical echo-suppressor layout suitable for telex.

In the modified standard echo-suppressor used in Great Britain, the operating time is approximately 10 milliseconds and the hang-over time 270 milliseconds. A diagram of the modified circuit is shown in Fig. 20.

(ii) Effect of line noise.

Line noise is most commonly of the form of short disturbances of considerable amplitude, similar to the atmospherics of radio engineering. The chief source of disturbance is in exchange switching operations, where momentary bridging of one line to another can occur. It has been found that, in practice, at least 95 per cent of the disturbances are of less than 2 milliseconds duration, and the majority of those are of less than 1 millisecond. A short disturbance may give either an " extra " or a " failure " in the received signals. If the disturbance is received whilst a character but no tone is being transmitted, the equivalent of a period of tone results. If the amplitude of the disturbance is large, the grid condenser in the receiver may be charged to

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* See Bibliography, (31).

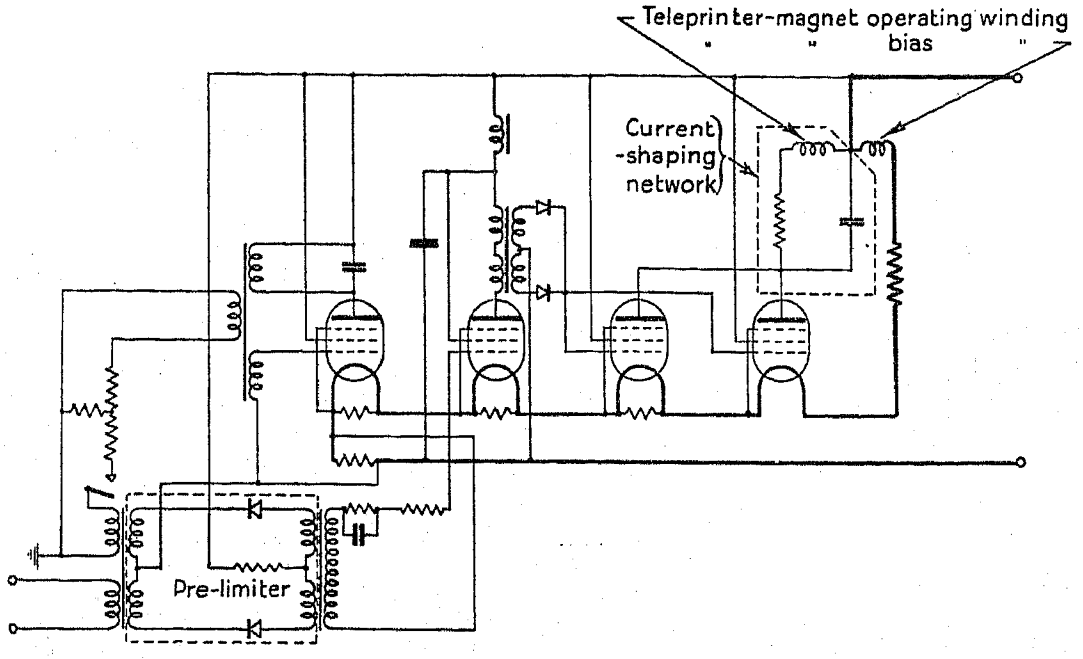

Fig. 21.—Experimental convertor embodying noise discrimination on a time basis

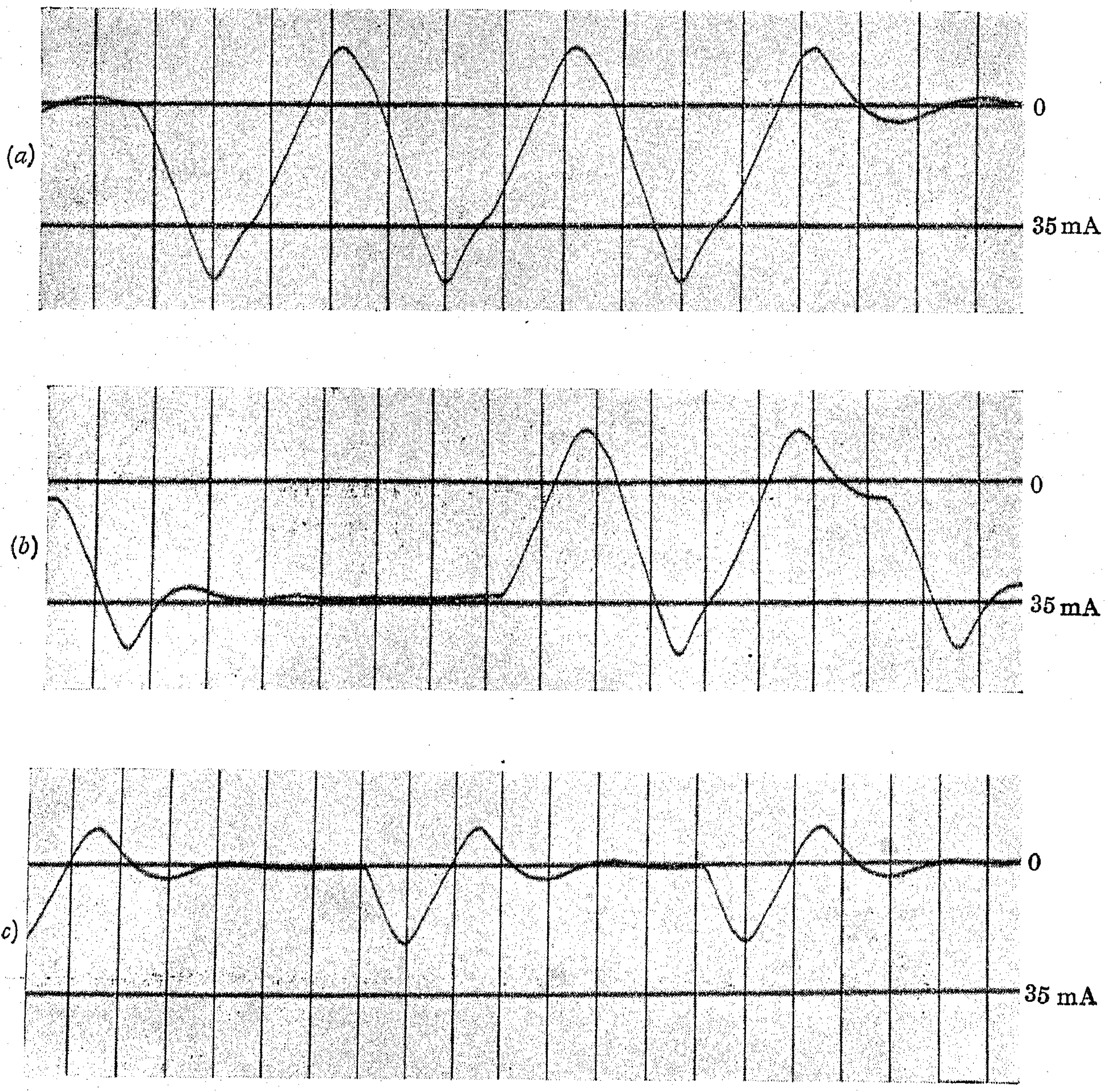

Fig. 22.—Current in teleprinter electromagnet winding, with armature clamped.

(a) Current on letter " Y " (S, MSMSM, M).
(b) Current on carriage return (S, SSSMS, M).
(c) Current in magnet: 0·5-millisecond disturbances. 10-millisecond timing lines.

such a point that the next voice-frequency signal is suppressed and the result is equivalent to a period of no tone. The amplitude of the disturbances is usually of the order of 2 volts, but in exceptional cases may reach 20 volts.

Discrimination between the disturbances and the voice-frequency signal can be made on an amplitude basis, on a frequency basis, or on a duration or time basis. Discrimination on an amplitude basis can only be made by reducing the absolute sensitivity of the receiver to a minimum. This requires that the transmitter input to the line be fixed at the maximum power permitted by considerations of repeater-overloading and of cross-talk. For telex services in this country the sensitivity required is such that the equipment must operate on an input of 0·1 volt, and for international working 0·05 volt. Thus, a number of disturbances remain which on an amplitude basis are liable to mutilate transmission.

As the total energy of a d.c. pulse is spread over an infinitely large number of frequencies, a certain amount of discrimination between signals and disturbances can be obtained by restricting the received band of frequencies. It follows also that it is impossible to discriminate completely, as part of the energy will undoubtedly fall within the transmission band. The result is that the disturbance received after the filter is of smaller amplitude but greater length than the original pulse, and the narrower the transmitting band width the greater is the effect on both amplitude and length. The restriction of the transmitting band therefore improves the signal/disturbance-voltage ratio, but the gain is limited by the band width necessary for transmission with a reasonable minimum of distortion. Thus, with a carrier frequency of 1 500 cycles per sec. and a band width of 400 cycles per sec., the amplitude of the disturbances produced by the application of a d.c. voltage from a low-impedance source is reduced in the ratio of about 4 to 1, but the length is increased from a very small value to about 3 milliseconds. The effect of a large proportion of disturbances is nullified, therefore, but the remainder which are still comparable in amplitude with the signal are more likely to result in false characters owing to their greater length and the consequently greater chance of interference with a particular operation of the receiving electromagnet.

Because of the short duration of the disturbances in comparison with the shortest signal element, duration forms the best basis of discrimination. This method can be applied by reducing equally the rates of growth and die-away of a signal, so that signals shorter than a certain length of time cannot operate the receiving relay. Fig. 21 shows how the system has been embodied in an experimental a.c./d.c. single-current convertor for use on telex circuits. The network in the d.c. output circuit produces such a wave-form in the change-over from M to S (mark to space), and vice versa, that a signal shorter than 7 milliseconds does not exceed the effective value of the bias current. As the retarding network comes after the limiting valve, the sensitivity to disturbances is not dependent on amplitude providing this is comparable with the normal maximum signal amplitude. The presence of a band-pass filter reduces the amplitude of the disturbance, and therefore to a certain extent guards against excessive charge being produced on the grid condenser.

Oscillograms of current in the teleprinter-magnet winding are shown in Fig. 22. Such disturbances do not operate the teleprinter whilst signals are not passing, but, if they occur during transmission, precipitate or retard operations of the magnet armature. The errors in transmission are therefore roughly proportional to the number of change-overs in the character; letters such as " T " (S, S S S S M, M) being almost immune, and letters such as " Y " (S, M S M S M, M) showing the greatest number of errors.

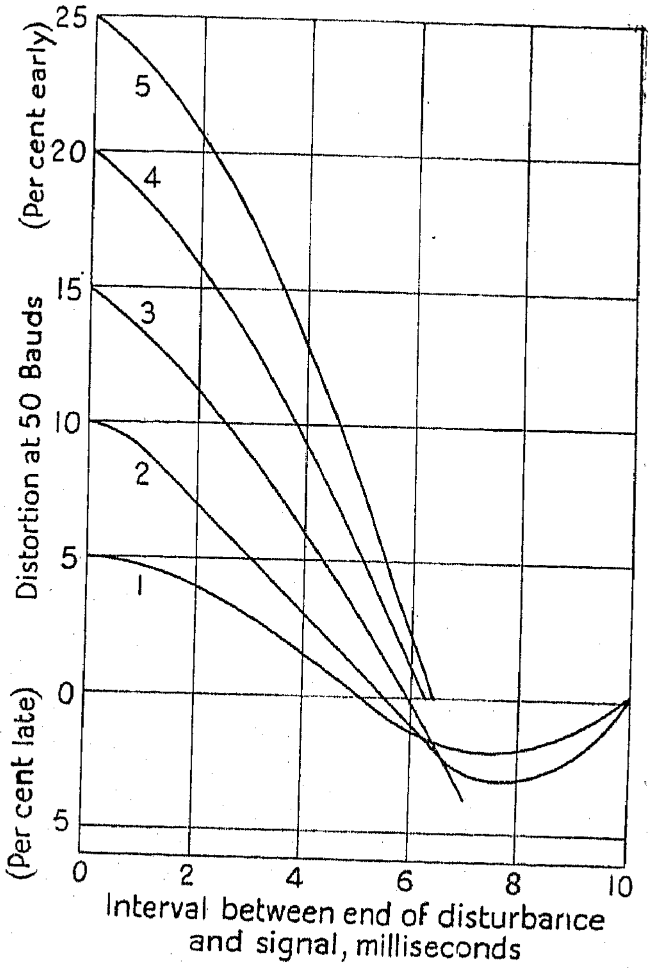

Fig. 23.—Effect of disturbance preceding signal.

The figures on the curves denote duration of disturbance, in milliseconds.

The effect of a disturbance immediately preceding or following a signal operation has been examined using apparatus embodying the circuit of Fig. 21, and the results are shown in the curves given in Figs. 23 and 24. In these curves it has been assumed that the amplitude of the disturbance is roughly the same as that of the signal, and therefore the suppression of a signal following a disturbance of greater amplitude has been ignored. Several interesting points are brought out by these curves. In the first place, if the disturbance precedes the signal operation the maximum distortion which results is equal to the length of the disturbance. Thus, with a band-pass filter having a transmitting band width of 400 cycles per sec. by which any short disturbance is lengthened to 3 milliseconds, the distortion of a M-to-S operation can reach a maximum of 15 per cent at 50 bauds, a figure which should be well within the margin of the receiver. Secondly, if the disturbance immediately follows a signal the distortion is again

15 per cent. A short interval between the end of the signal and the disturbance can introduce distortion of between 15 and 37 per cent, depending on the duration of the interval, but provided that the interval is less than 3 or greater than 7 milliseconds (the shortest interval in which the relay will operate) the distortion is not more than 25 per cent, a not-unreasonable figure for the margin of the receiver. In the worst cases, the distortion due to a disturbance at a certain interval after the end of a signal is more than it would be if there were no interval and the disturbance were increased in length by the duration of the interval. For example, a 5-millisecond disturbance after an interval of 7 milliseconds results in 76 per cent distortion; whereas, if there were no interval and the disturbance were increased to 12 milliseconds, the distortion would be only 60 per cent. To a lesser degree, this is also the case for shorter intervals; and is due to the combination of the transients produced by the signal and the disturbance delaying the fall of current in the magnet winding.

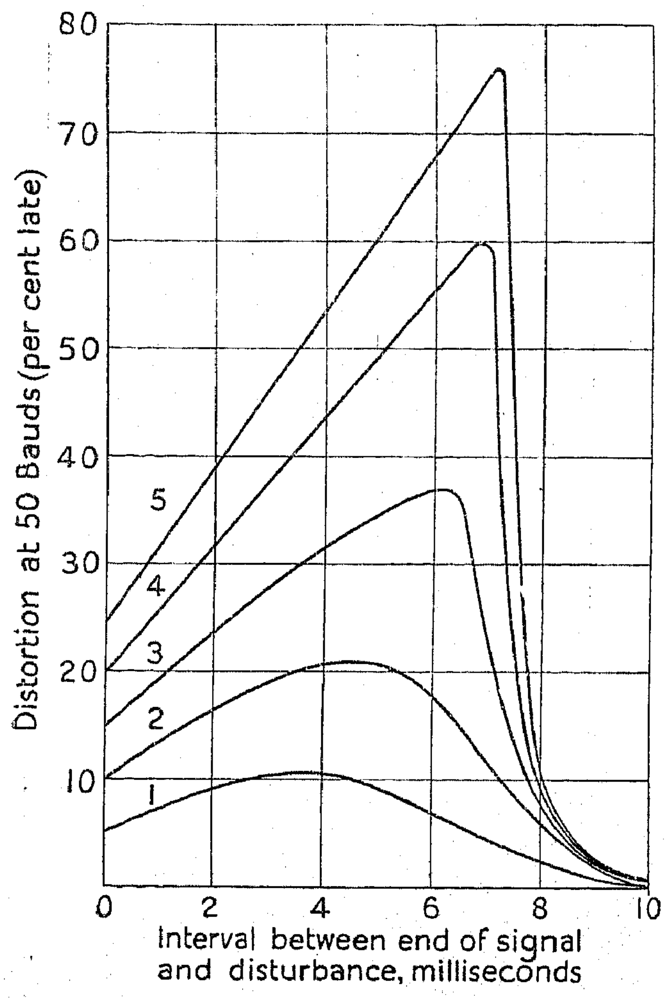

Fig. 24.—Effect of disturbance following signal.

The figures on the curves denote duration of disturbance, in milliseconds.

The curves also show that, if possible, the transmitting band width should be such that short disturbances are lengthened to not more than 2 milliseconds in order that the distortion may not exceed 25 per cent for any position of the disturbance. This requirement can be met by increasing the band width of the receiving filter or by cutting out the filter, but there remains the possibility of disturbances of large amplitude charging the grid condenser and suppressing telegraph signals following the disturbance. This effect can be counteracted by the use of a received-current-limiter, which precedes the voltage-limiter in the convertor, as is shown in Fig. 21. The object of the current pre-limiter is to limit the grid-condenser charging current to the maximum signal current which the convertor is designed to receive. The pre-limiter itself consists of a network containing copper-oxide rectifiers which are in series with the receiver and carry direct current. The a.c. signal is superposed on the d.c., increasing the instantaneous value of the total current in one rectifier and reducing it in the other. As the current in one rectifier approaches zero, the series impedance between the line and the convertor increases rapidly, and therefore the peak value of the signal current is limited practically to the direct current in the rectifier circuit.

Although this charging-current pre-limiter limits also the signal voltage received by the convertor, its effect, in this instance, is not the same as that of the widely used voltage-limiter which operates by producing a shunt across the receiver when the level of the received signal exceeds a predetermined value. The grid-circuit-limiter of the receiver operates as a voltage-limiter on a very short signal or disturbance and is, in fact, more effective than a voltage pre-limiter could be, because the former limits the signal to the minimum receiving level whereas the latter can only be designed to limit the signal to the maximum receiving level if distortion of the signal is to be avoided.

(5) DIRECT-CURRENT TRANSMISSION

So far as the British inland service is concerned, direct-current methods have become of considerably less importance since the extension of multi-channel voice-frequency working. Apart from short local lines, and extensions from voice-frequency systems, direct-current working is mainly employed for the utilization of by-product circuits in telephone cables, and for working on submarine telegraph cables to the Continent and numerous islands off the shores of Great Britain. The by-product circuits in use are phantoms in star-quad telephone cables and double-phantoms in multiple-twin telephone cables. Details of the methods used when such circuits are employed for the provision of private wires have already been published.*

In the case of extensions from the voice-frequency system the windings of the voice-frequency transmitting relays are connected through a fixed resistance of 3 000 ohms to earth while the operating current is supplied over the line from a double-current earthed ± 80-volt battery via the transmitting teleprinter contacts. In the reverse direction the voice-frequency receiving relay transmits double current from an earthed ± 80-volt battery to line and eventually to the teleprinter electromagnet or receiving relay. Under these conditions it is found that at teleprinter speeds a considerable length of line (actually about 30 miles of 20-lb. telephone conductor or the equivalent) can be used without appreciably increasing the overall distortion of the circuit above that of the channel itself. This is without the inclusion of additional relays in the circuit and with simple filters inserted to prevent interference with telephone circuits. By inserting suitable receiving relays in the two sides of the circuit and connecting the teleprinter electromagnet and the voice-frequency send relay to the local contacts of these relays the length of line can be increased to upwards of 100 miles of 20-lb. conductor or the equivalent, without appreciably increasing the overall distortion of the circuit above that of the voice-frequency channel alone.

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* See Bibliography, (27).

(a) Sub-audio (Infra-acoustic) Circuits on Submarine Cables

It has not been found necessary to make use of sub-audio circuits in the British Isles, with the exception of several cases in which submarine cables are involved and the provision of special equipment is warranted. Such a case is that of the London–Jersey duplex teleprinter circuit, which is composited with the Channel Islands telephone circuit on a single-core unloaded submarine cable. Two duplex teleprinter circuits have also been installed on the continuously-loaded submarine telephone cable between Blackpool and Port Erin (Isle of Man).* These circuits are noteworthy for the low transmitting voltages used (approximately 7 volts) in order to avoid the risk of affecting the characteristics of the loading material on the cable conductors, and so giving rise to cross-talk on account of minute changes in inductance. The terminal arrangements at Blackpool are shown in Fig. 25. Rectifiers were used to provide the line current, to avoid the necessity for special insulated batteries for each circuit. A sending-end inductive shunt was used as a convenient method of reducing distortion and compensating for the relatively high resistance of the transmitting portion of the circuit. The potentiometer and shunt entail a considerably higher current output from the rectifier than is used in the line, but this is not in fact of practical importance. Other points of interest are the artificial line used in place of the conventional balance, the necessity for smoothing the vibrating circuit of the receiving relay, and the transformer in the line circuit. The last item is introduced to prevent the telegraph apparatus from producing a loss on the double-phantom telephone circuit which works on the two phantom circuits on which the telegraphs are composited. Smoothing of the vibrating circuit is provided to prevent noise on the telephone circuit.

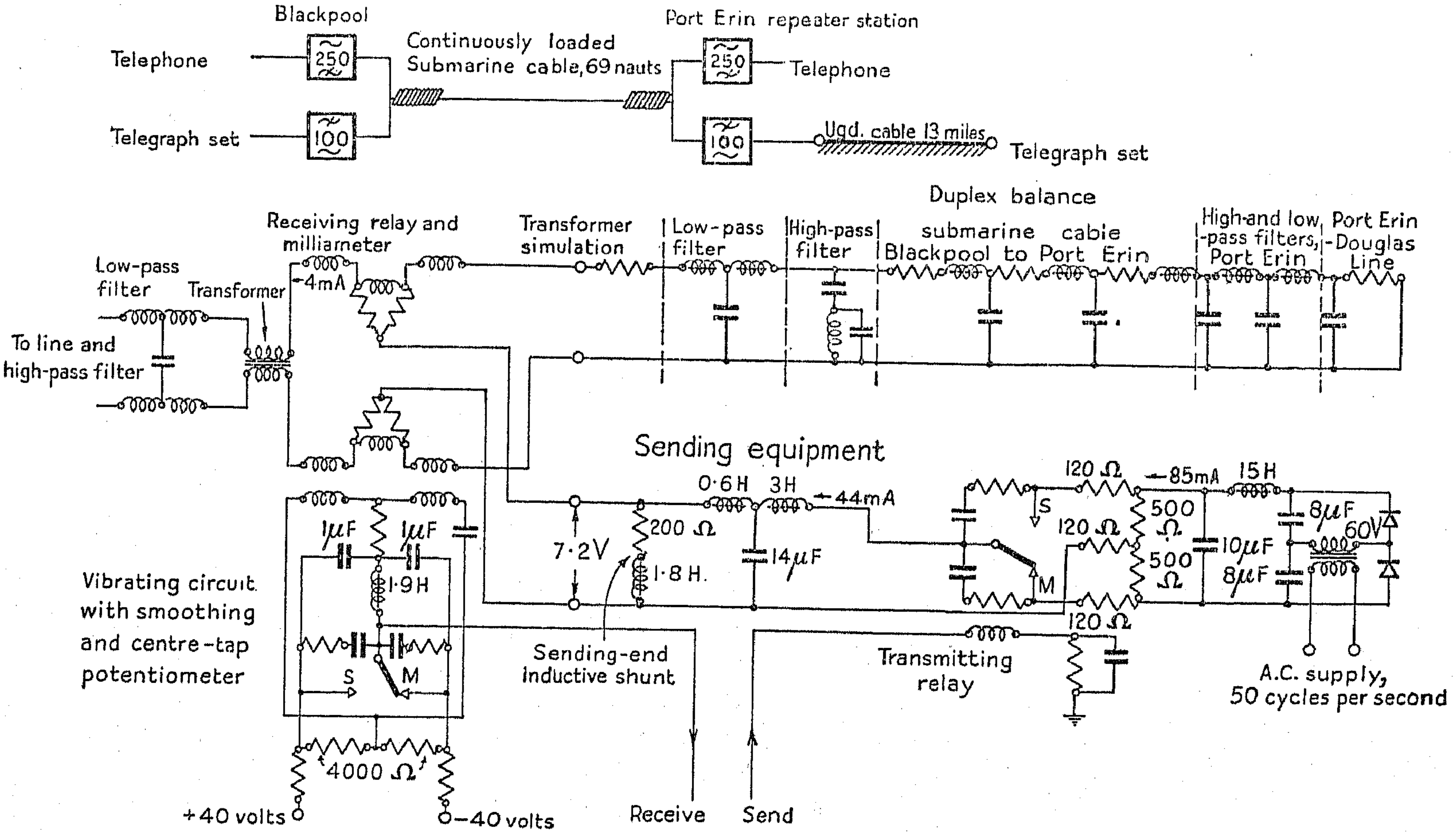

Fig. 25.—Blackpool–Douglas sub-audio teleprinter circuit. Line diagram and circuit arrangement of equipment at Blackpool.

A sub-audio case of a somewhat different character was that in which a telephone circuit between Jersey and Guernsey was obtained by making use of two cores of a 3-core telegraph cable already in use for telegraph circuits from Jersey to London, without change in the operating conditions of the telegraph circuits. The use of the normal 80 volts on the telegraph circuits entails surge currents up to 200 mA in the inductances of the battery-circuit smoothers, but by paying special attention to the design of the filter coils in the telegraph circuits it has nevertheless been possible to raise the cut-off frequency of the line filters to 200 cycles per sec. The coils are made up on a laminated mumetal core and for a 0·56-henry coil having a d.c. resistance of 7·5 ohms the change of inductance at 50 cycles per sec. for currents from zero up to 200 mA was less than 1 per cent. The result of the relatively high cut-off and the large surge currents possible has been that the characteristics of the telegraph circuits are essentially unaltered. Tests showed that with the arrangements adopted, an incoming telephone level, at the junction of the high- and low-pass filters, of as low as −35 db would still give a satisfactory signal/noise ratio on the telephone channel.

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* See Bibliography, (30).

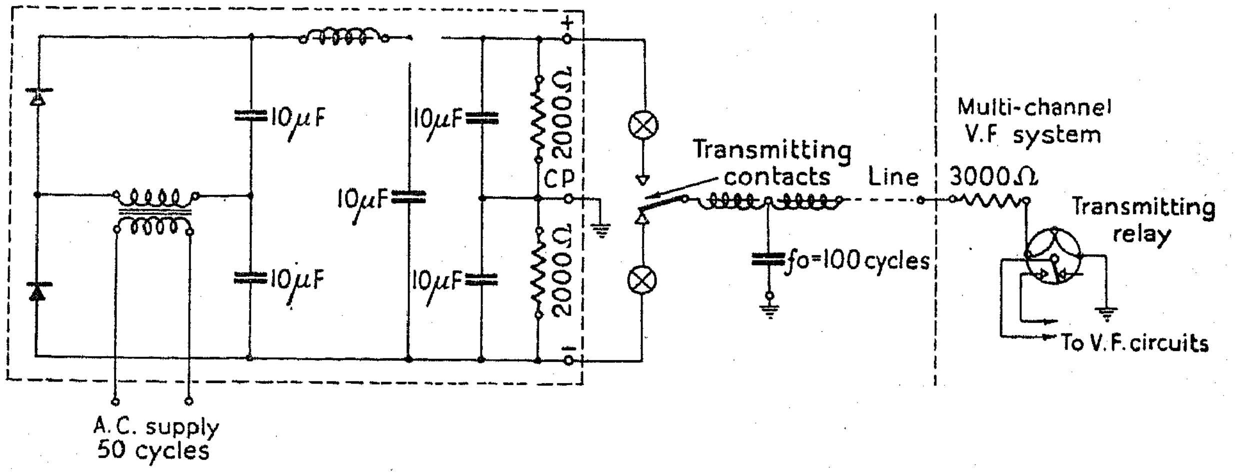

Fig. 26.—Rectifier unit for direct-current extension from multi-channel voice-frequency system.

(b) Use of Rectifiers for D.C. Telegraph Currents

All-mains teleprinter sets have been in use at small offices having a.c. power supply for some years.* Where a d.c. power supply only is available central battery working has been resorted to, but small rotary transformers are now being introduced for obtaining double-current supply. The a.c. all-mains arrangement makes use of a rectifier unit having an output of approximately 110 volts at 0·75 amp. The arrangement is such that the power for driving the teleprinter motor and for a double-current line and local supply of ± 55 volts are all obtained from one rectifier. The use of a single unit in this way is permitted by the fact that the high-capacity rectifier necessitated by the motor has a comparatively low internal resistance. Rectifier units of considerably lower capacity than the foregoing have been developed for the exclusive supply of the telegraph currents where it is not desired to use the common rectifier unit referred to above, for example, on account of the non-standard voltage of (55 + 55) volts.

Fig. 26 is a diagram of one form of rectifier unit used for the supply of ± 80 volts for working into a multi-channel voice-frequency terminal over a direct-current line. The rectifier units are joined up on the voltage-doubler principle, the double-current supply being obtained by means of a potentiometer. This method avoids any possibility of battery bias, and the rectifiers are used somewhat more efficiently than with the bridge scheme. The value of the potentiometer (2 000 ohms + 2 000 ohms) has been kept high to avoid an unduly heavy load on the rectifiers. The 10-μF condensers shunting these resistances reduce the loss in transmission efficiency on account of the high resistance of the potentiometer and rectifier.

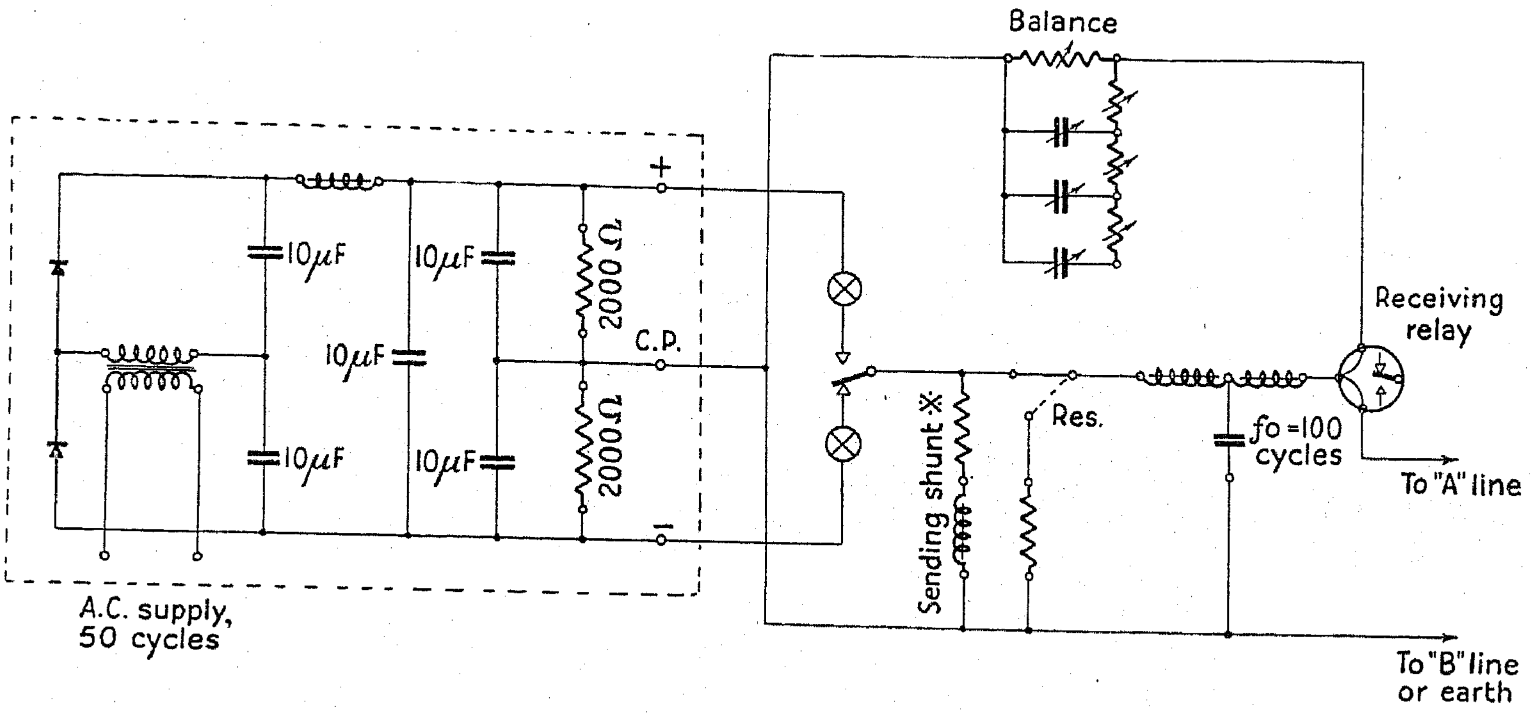

Fig. 27.—Rectifier unit for duplex working (loop or earth).
※ Inductance only required on longest lines.

Table 3 gives the output characteristic of the rectifier unit shown in Fig. 26.

It will be observed that the voltage on the off-load side of the potentiometer rises considerably This voltage, however, never appears across the line terminals, and in fact the shape of the line-voltage curves is identical with that obtained using a battery. Rectifier units of this and similar types are also being used to provide the line and local currents on teleprinter private wires. For working over long distances, and also where a lower line voltage is required, the unit can be used in the manner shown in Fig. 27, which is a diagram of the sending end of a differential duplex circuit with rectifier supply. A sending shunt is used which may consist of a plain resistance or of a resistance and inductance, and, by proper adjustment of this shunt, transmission equivalent to, or better than, normal battery operation can be secured.

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* See Bibliography, (38).

Table 3

Volts across potentiometer		Load current
Working side	Idle side	
		mA
95	125	15
75	135	30
50	150	50

Table 4

Type of circuit	Length	$K \times R$	Sending shunt		Steady line current	Steady line voltage	Characteristic distortion at 50 bauds
			L	R			
	miles	μF × ohms	henrys	ohms	mA	volts	per cent
40-lb. double-phantom.. ..	260	108 000	9	800	10	43	5
	350	192 000	11	440	5	28	8
25-lb. phantom	120	80 000	3	400	5	23	5
	180	180 000	7	560	4·75	33	8
40-lb. loop	220	130 000	0·7	800	4	46	5

Typical results obtained in the laboratory on different types of artificial underground cable are given in Table 4.

(6) TESTING

(a) Frequency Control and Synchronism

Modern communications engineering is becoming more and more dependent on the accurate control of speed and frequency. A telegraph circuit working on a multi-channel voice-frequency circuit is an instance of this. The motors of the teleprinters themselves must all run as nearly as possible at equal speeds in order to have maximum margin available to cover line and incidental distortion. The multi-frequency generators must run at correct speed in order that the frequencies generated shall lie in the centre of the filter bands and so allow room for the signalling side-bands. If the multi-channel system itself is operated on a carrier channel the frequencies of the oscillators in the modulating and demodulating equipment must again be equal for the same reason.

(i) Teleprinter speeds.

Steady improvement has been made in the maintenance of correct teleprinter speed, and it is now safe to say that the speeds of co-operating machines seldom differ by more than 1 per cent. It was often claimed in the early days of teleprinter working that speed differences of 4 or 5 per cent could be tolerated, but clearly it is preferable to run at correct speed and retain a margin to meet less tangible sources of trouble.

Speed is checked by means of stroboscopes and synchroscopes. The former were originally the sole method of speed testing, and consisted of viewing a mark on a rotating shaft of the teleprinter through the window of a tuned vibrating reed. The accuracy of the test is not high, and synchroscopes have been introduced which have resulted in a marked improvement in the general accuracy of teleprinter speeds. The circuit of the synchroscope is shown in Fig. 28. The teleprinter to be tested may be either adjacent to or remote from the synchroscope panel; the letter "V" or other suitable character is transmitted continuously from the teleprinter transmitter (either directly or over the telegraph circuit in the case of a distant machine) into relay B of the synchroscope panel. Relay B, and also, therefore, relay A, operate once per character, the latter connecting the power supply intermittently to one side of a series of six neon lamps arranged in a circle. These lamps are energized in rotation from a brush driven from a mains-operated synchronous motor but geared down to the standard speed of the teleprinter transmitter. If, therefore, the teleprinter speed is correct, the same lamp flashes with each character transmitted. If, however, it is fast or slow, the flashes rotate at a speed which can be readily estimated and translated into the percentage speed error of the teleprinter. It will be observed that the method is dependent on the accuracy of the supply frequency. Experience has so far indicated that this may be relied upon to 0·2 per cent, which is adequate for the present purpose. To cover cases where controlled-frequency a.c. mains are not available, a 50-cycle valve-maintained tuning-fork unit has been developed.

The ultimate solution to the question of teleprinter speed control may be found in the use of synchronous motors. The problem of design is not readily capable of solution, however, owing to the conflicting requirements of noise, space, heating, starting torque, and running torque, while the difficulty of providing an accurate alternative supply in the event of mains failure must be borne in mind. A quantity of motors are now under field trial, but a decision as to their general use has not yet been made.

(ii) Multi-frequency generators.

These are governed electromechanically to an accuracy of ± 0·25 per cent. At the lowest frequency (420 cycles per sec.) this error amounts to only ± 1·05 cycles per sec., but at the highest of the 18 frequencies (2 460 cycles per sec.) the error becomes 6 cycles per sec., which is the limit laid down by the C.C.I.T. (*Avis* No. 511).* It will be seen that the necessary percentage accuracy of the frequency of the carrier increases in proportion to the frequency. It is unlikely that greater stability of a direct-current-driven multi-frequency generator than ± 0·25 per cent can be obtained in practice, and therefore if it is desired to continue the normal series of channels at 120-cycle spacing appreciably above 2 460 cycles per sec. it is best to do this on a carrier basis.

In practice the multi-frequency generators are checked stroboscopically from a neon lamp flashing from a stable oscillator. The frequency of the oscillators is 1 020 cycles, corresponding to the 6th-channel frequency. This channel is normally used as an engineering speaker circuit on one of the systems between main voice-frequency centres, and the oscillators at the provincial centres are checked weekly against this channel from London. The ultimate standard at London is a thermostatically-controlled valve-maintained 1 020-cycle fork. A successful substitute which is used where the above method cannot be adopted is to compare the tone of a good-quality 1 020-cycle tuning fork with that of the 1 020-cycle generator supply in a headgear receiver.

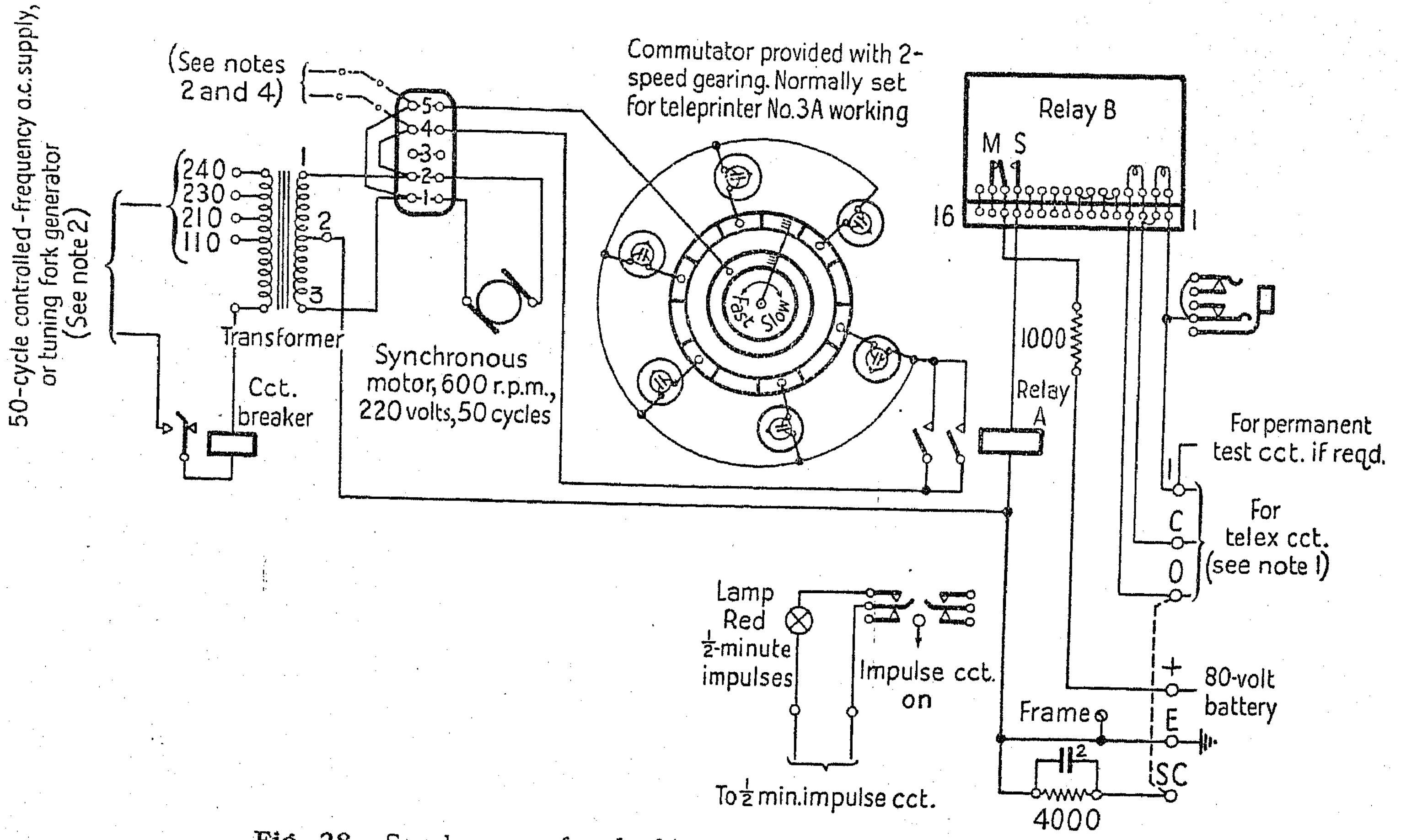
50-cycle controlled-frequency a.c. supply, or tuning fork generator (See note 2)
(See notes 2 and 4)
240
230
210
110
1
2
3
Transformer
Cct. breaker
5
4
3
2
1
Synchronous motor, 600 r.p.m., 220 volts, 50 cycles
Commutator provided with 2-speed gearing. Normally set for teleprinter No.3A working
Fast
Slow
Relay B
M S
16
1
1000
Relay A
For permanent test cct. if reqd.
I
C
O
For telex cct. (see note 1)
+
80-volt battery
E
SC
Frame
2
4000
Lamp Red
½-minute impulses
Impulse cct. on
To ½ min. impulse cct.

Fig. 28.—Synchroscope for checking transmission speeds of teleprinters.

NOTES.

1. For telex circuit connect tags Nos. 3, 4, and 5 of convertor to I, C, and O, respectively, and remove strap shown dotted.
2. When the supply is direct current, the transformer input should be connected to a tuning-fork generator and the power supply for the lamps obtained from a separate d.c. supply. Straps Nos. 1 to 5 and 2 to 4 on connecting block should be removed and the d.c. supply connected to Nos. 4 and 5.
3. For d.c. supply of 200 volts or over, or for any a.c. supply, 220-volt lamps should be used.
4. Where 110-volt d.c. supply only is available, the power supply for the lamps should be 160 volts, obtained from a 80 V + 80 V battery, in which case 110-volt lamps should be used.

(b) Telegraph Distortion Measuring Sets

The modern method of measuring and checking the performance of telegraph circuits is by observing the time distortion suffered by certain specific test signals when transmitted over the channel. This permits of an exactness in the setting-up and maintaining of channels which was never secured by the older methods using the telegraph apparatus itself to check the working of the channel. The independent and indisputable nature of the check given by telegraph distortion measurements has been of great value in both the installation and the maintenance of the voice-frequency network. Individual channels are set up independently of the system of telegraphy which may be worked on them when extended to an instrument room or renter's office, and also independently of the fact that they may be required to form one link in a series of tandem-connected channels.

Stroboscopic distortion measuring sets have been found the most convenient type for measuring line distortion.* In these sets the timing of the received signals is measured by means of radial flashes displayed on a circular time-base, the flashes being arranged to occur at the instants of modulation, i.e. when the receiving-relay armature moves across to the opposite side. The period of the time-base is arranged to be such that when the signals are distortionless the flashes are superposed. When distortion is present the flashes which should occur in the one place are spread over an arc, the extent of which gives a measure of the distortion present. A schematic diagram of the connections of the distortion-measuring set which is installed at all multi-channel voice-frequency terminals is given in Fig. 29. The stroboscope takes the form of a cathode-ray tube on the screen of which bright radial flashes denote the operations of the receiving relay. The circular time-base is produced by means of the oscillator and a phase-splitting resistance and condenser. The test signals are generated by a special transmitter designed to give a distortionless output. The transmitter gives signals having the following ratios of mark to space: 1/1, 2/2, 5/1, and 1/5. The test word "Paris" in morse, either "straight" or "reversed," is also available. These signals have been found to be sufficiently varied to meet all ordinary requirements in the setting-up of telegraph channels, but the standardization of a series of signals is under consideration by the C.C.I.T.†

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* See Bibliography, (6).

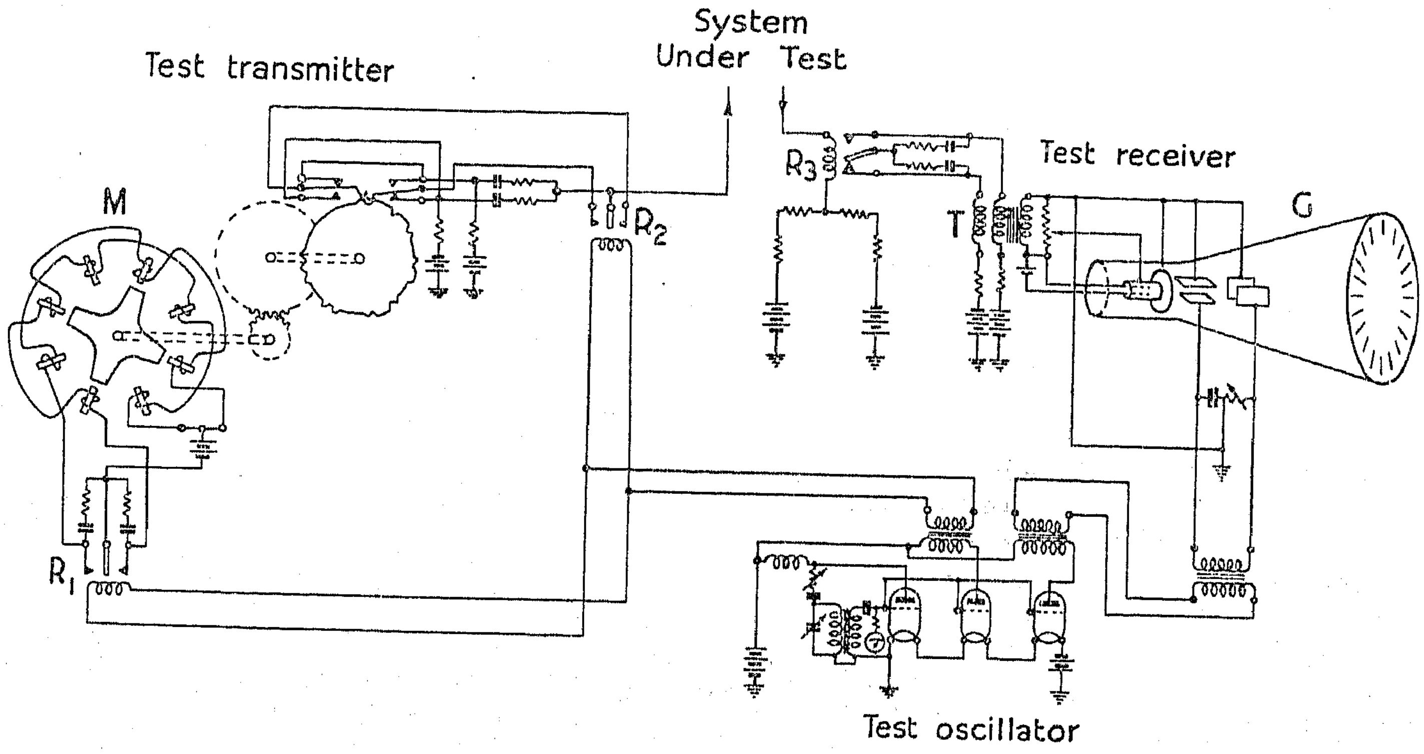

Fig. 29.—Telegraph distortion measuring set.

The use of an oscillator for driving the transmitter and receiver enables tests to be made over a wide range of telegraph speeds (usually 30 to 120 bauds) and facilitates adjustment of speed when the apparatus is receiving from a distant distortion testing set.

(c) Teleprinter Distortion and Margin Tester

Complementary to the above line-testing distortion set, a tester specifically designed for testing teleprinter circuits and apparatus has been introduced.‡ The tester provides means for: (i) checking the performance of a teleprinter transmitter; (ii) measuring the distortion in the lines and associated equipment; (iii) checking the performance of the receiving mechanism of the teleprinter, and measuring its margin.

In this tester, the period of a revolution of the stroboscope is equal to the duration of a whole teleprinter letter instead of one element; the flashes are therefore distributed round the scale at intervals corresponding to the modulation elements of the teleprinter signal. The transmitter is of the distributor type and sends continuous repetitions of any signal in the teleprinter code, as well as 1 : 1 reversals. The tester is shown schematically in Fig. 30. Five "code keys," wired to segments of the distributor, are used to set up the desired teleprinter signals. The sliding segment is insulated from the "start" segment, part of which it masks, and is used for varying the length of the start signal from normal. This is to enable varying amounts of distortion to be introduced into the transmitted signals, so that by sending these signals into a teleprinter the limit of permissible distortion before errors occur may be determined, thus giving a measure of the margin of the machine. The stroboscope consists of a neon tube mounted behind a radial slot in a rotating disc. Two methods of flashing the lamp are used. The first of these causes an instantaneous flash each time the receiving-relay armature moves on to the opposite contact. This method is used for distortion measurements, the distortion being measured by the displacement of the flashes from their true position on the scale, the flash corresponding to the "start" signal being taken as the reference point. A typical display for a distorted signal is shown in Fig. 31. The points at which the flashes would occur on a distortionless signal are shown dotted. The second flashing circuit is used for testing for transit time and breaking or bounce at the transmitting contacts of teleprinters or telegraph relays. In this case the lamp is flashed immediately the moving contact leaves one side and is not extinguished until it reaches the opposite contact, and the breadth of the flash indicates the length of the transit time. Also, if breaking or chattering is present, flashes are produced each time this occurs.

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* See Bibliography, (35) and (37).

† *Ibid.*, (5). The signals have now been standardized. See Bibliography, (6), *Avis*, No. 311.

‡ *Ibid.*, (36).

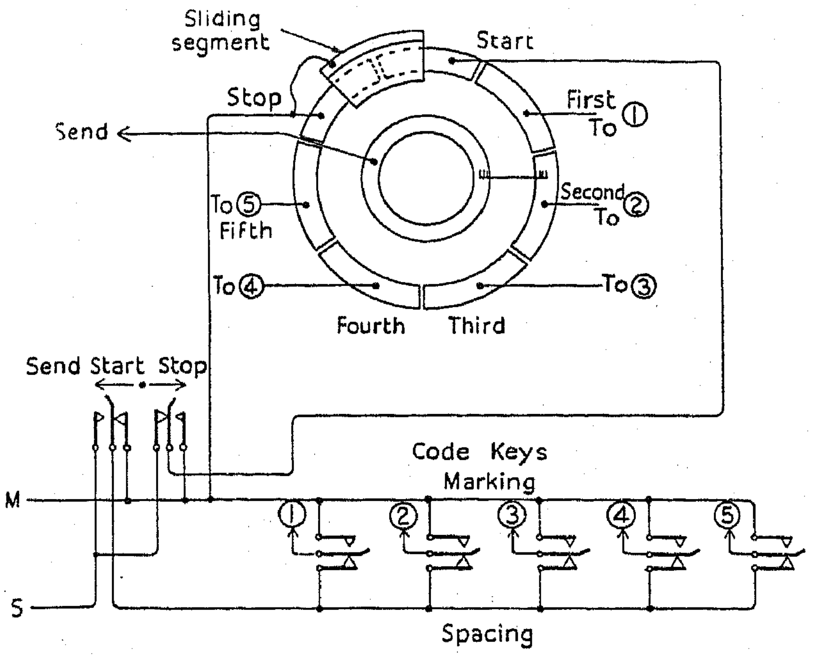

Fig. 30.—Teleprinter distortion and margin tester transmitter.

The tester is being used in mechanics shops to check the transmitting and receiving mechanisms of teleprinters and to determine the causes of inefficient operation. It has also found considerable use in connection with the design of teleprinter circuits and mechanisms, as for this purpose the full stroboscopic display of a character is advantageous. In certain cases it is useful to send the teleprinter letters from the transmitter at a lower rate than normal, a period of marking or spacing of 150 milliseconds or more being interposed between the letters, and this facility has been provided on sets used in laboratory investigations.

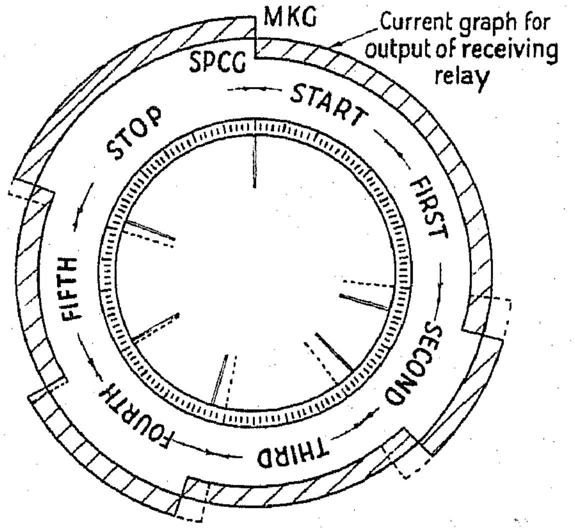

Fig. 31.—Teleprinter distortion and margin tester stroboscope. Typical display of received signal (letter " R "); distortionless signal shown dotted.

(d) Automatic Testing Transmitter

This is an arrangement whereby continuous repetitions of a test message in teleprinter code are provided for testing teleprinters and teleprinter circuits; it is particularly useful when frequent or protracted tests are required. Reversals are also available, as well as the usual test sequence of alternate " R "s and " Y "s. Means are provided whereby, if desired, the signals may be given marking or spacing bias up to 25 per cent. The device, which was originally developed to enable a telephone operator to communicate with a telex subscriber who has his line switched to teleprinter, is shown schematically in Fig. 32. The transmitter is a distributor having one segmented ring to give signals in the 7½-unit code and a second segmented ring for reversals. A 7-bank, 100-contact, rotary switch is made use of, and when sending the test message the wipers are stepped once per revolution of the distributor via one segment of the reversals ring. This segment is chosen so that the wipers move while the stop signal is being sent out. The contacts of banks Nos. 1 to 5 are wired to positive and negative battery according to the code for the message, while the wipers are wired to the five code segments on the distributor. A homing arc is provided so that before the first message is sent out upon the operation of the " message " key, the switch

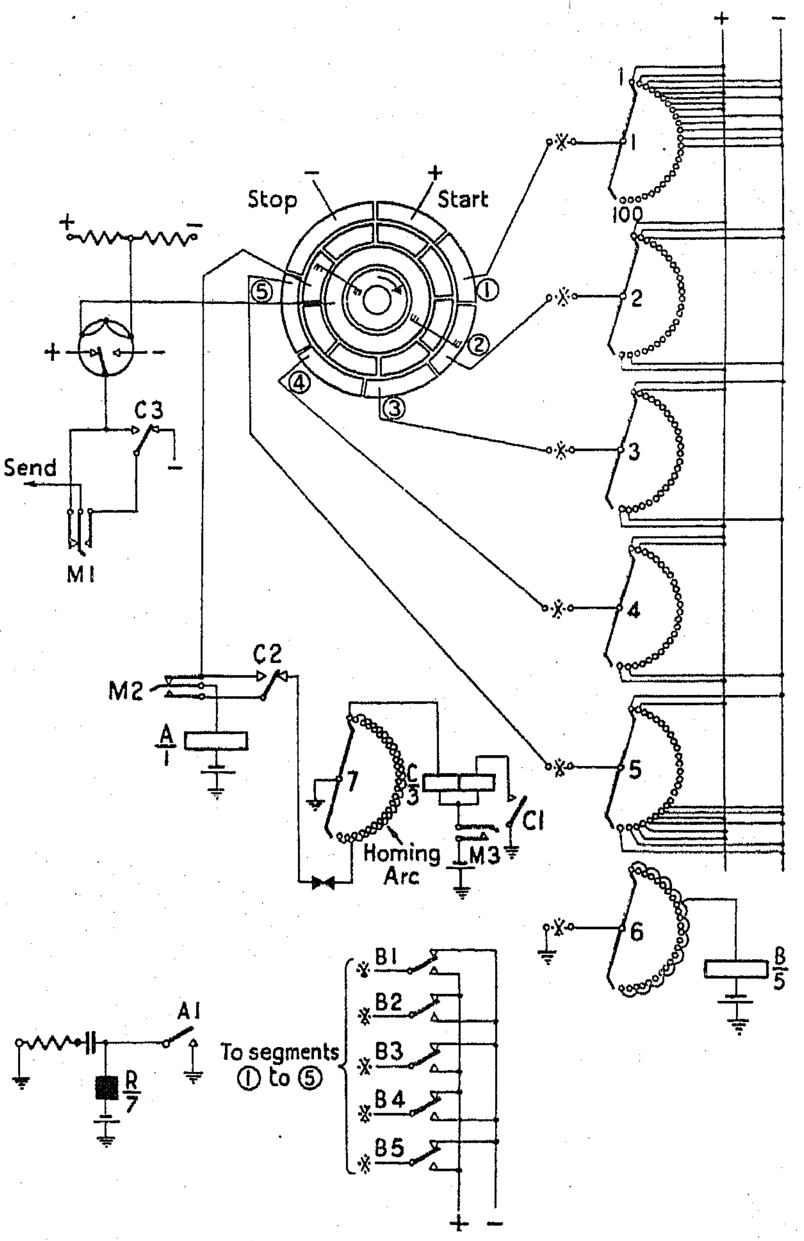

Fig. 32.—Schematic diagram showing principle of operation of automatic test transmitter.

M1, M2, M3 = Contacts of message key.
⁂ Denotes connections via contacts of " RY " key (not shown).

returns to the home position, whereupon relay C operates and locks. When relay C operates, the transmitting relay and impulsing circuit are switched through and the message commences. The "RY"s are obtained by the operation of a key which connects the contacts of relay B to the distributor segments in place of wipers Nos. 1 to 5. This relay operates on alternate contacts of bank No. 6, and its contacts are wired so that when normal the code for letter "Y" is obtained and when operated the code for letter "R." The switch steps once per revolution of the distributor, so that the letters "R" and "Y" are sent out alternately.

(e) Testing of Telegraph Relays

While the stability of modern telegraph relays is such that adjustments are infrequent, the loss of margin that can result from maladjustment warrants the use of special relay testing equipment. The C.C.I.T. has laid down (*Avis* No. 618)* principles for the adjustment of relays which have been embodied in the relay test tables and test panels used in the British Post Office. The tests cover the continuity and sensitivity of the line windings, neutrality, contact time, and, when applicable, continuity and neutrality of vibrating coils.

(7) TREND OF DEVELOPMENT

In the case of telephony, voice-frequency signalling methods and improvements in transmission technique have led to development in the direction of extending the automatic system to include the trunk circuits, so avoiding the delays and costs of intermediate operating. Similarly in telegraphy, the elimination of probably 50 per cent of the operating transactions and delays would be possible by means of through automatic switching from the office of origin to the delivery office.† The present voice-frequency network makes a framework for such a scheme which would have been completely impracticable under the old physical line conditions. Telegraphy is now in a position to share in the rapid advances made in the telephone field, and its development need no longer suffer from the isolated nature of the plant and technique upon which this important branch of the telecommunications art until recently depended.

Although the recent reduction in telegraph rates has reawakened interest in the public telegraph service and has resulted in an increase in inland traffic of some 36 per cent, it is in the private teleprinter services where continual progress is assured. The teleprinter, with its typewriter keyboard, the elimination of the distance factor by voice-frequency methods, the stability provided by underground cables, and cheaper private-wire telegraph rentals, have placed at the disposal of the commercial world a new tool well in keeping with its modern tendencies.

In conclusion, the authors wish to thank all those who have directly or indirectly assisted them in the preparation of this paper; and also Sir George Lee, the Engineer-in-Chief of the G.P.O., for permission to publish the information contained in it.

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DISCUSSION BEFORE THE INSTITUTION, 19TH NOVEMBER, 1936

Mr. F. Gill: A portion of what I am about to say has been derived from the paper read before The Institution by Donald Murray in 1924.*

The frequent references in the present paper to the recommendations of the C.C.I.T. constitute a testimony to the very valuable work performed by that body.

The authors use the phrase "If . . . with the teleprinter as a mere accessory of the telephone. . . ." If the teleprinter is an accessory of the telephone system, I presume it must be based on economy; but this method seems to require that one shall use telephone long-distance circuits, say, between London and Glasgow, and therefore be charged the same fees as for telephone circuits, thus losing the economy of the narrow-band telegraph circuits. I should have thought that there was a better economic case for an independently-operating telegraph system.

Telegraph history, as presented in documents, is gloomy. The figures for the 12 years ending March, 1935, show a decrease in gross income of nearly 30 per cent, but in spite of this the yearly deficit has been improved by 14 per cent. The number of telegrams decreased from 71 millions to 44 millions; if we add the 36 per cent mentioned by the authors, then we may say that the traffic has decreased from 71 to 60 millions. But there are about 700 circuits (private and telex lines), which do not send ordinary telegrams, yet transmit messages telegraphically. The total number of telegraph messages sent over these lines must be a considerable volume of traffic, which seems to have escaped the records. I think the total volume of communications transmitted over the telegraph equipment must be greater than appears in the official records.

All over the world we get the anomaly that telephone systems can be made to pay whereas telegraph systems cannot; and one naturally asks, why? Is not telegraph plant very much the same as telephone? Analysing the functions of the two services, one arrives at these fundamental differences: the telegraph constantly repeats its message; the telephone does not—it switches end to end. The telegraph does a lot of clerical work, and it provides a stenographer, who types the message; the telegraph service must charge for the stenographer's time; whereas the telephone subscriber meets that cost—his own time—without appreciating it. The telegraph service delivers by hand; the telephone delivers instrumentally. The telegraph service checks and accounts, in terms of words and distance (when necessary); the telephone service pays no regard to words—it checks in terms of calls, time, and distance (when necessary). The telephone service is very accessible, and is very quick compared with the telegraph. The latter, on the other hand, has an advantage in that it can deliver the answer in the absence of the person to whom the communication is directed. Operating and traffic expenses are about three times as great in the telegraph service as they are in the telephone service; and apparently the public is unwilling to pay a proper charge for the additional services which the telegraph performs.

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* *Journal I.E.E.*, 1925, vol. 63, p. 245.

If this is true, does it not point to the desirability of gradually working towards a uniform system such as the authors have envisaged, with one telegraph switching system and one telegraph trunk network available to both the operator and the subscriber? This would be an attempt to get rid of some of the special handicaps under which the telegraph system is working, and to benefit by the experience of the telephone service.

Sir George Lee: This paper describes the middle phase of recent developments of telegraph transmission in this country. The first phase—the introduction of the teleprinter, coupled with the reorganization of the apparatus rooms and the installation of conveyor belts, etc.—was covered by Mr. R. P. Smith in 1932.* Following on that phase, which created a very large improvement in the telegraph service in this country, as it has done elsewhere, the application of voice-frequency transmission to telegraphs was taken in hand, and that is the work which is described in this paper. Much valuable work has been done by the authors and their associates in the application of what may be called "telephone technique" to telegraphs, and the paper gives a very clear indication of the advances which have been made possible by this means. The application of voice-frequency methods has improved the reliability and accuracy of the service, but in addition it has very considerably cheapened the cost of line services. Allowance has to be made for the cost of the terminal equipment, but the line plant itself carries as many as 18 telegraph channels on one telephone channel, leading, as is obvious, to very much reduced cost.

The cheapening of line plant has made possible the third phase, which is briefly referred to in the concluding part of the paper. The reference is to the application of automatic-telephone type switching to telegraphs, on which experiments are being made at the present time.

We have had various switching systems before, which have died a natural death, but none which had relatively unlimited lines giving a no-delay service and automatic dialling. At present, if a telegram is handed in at a teleprinter office "A," it is usually transmitted to a zone centre office "B," where it is taken down on one teleprinter and passed over a conveyor belt to another teleprinter on an outgoing circuit to zone centre "C," where it is again taken down and retransmitted to the distant reception office "D." Under the new scheme "A" will dial "D" direct with a 3-figure code and be through in a few seconds to that office, where a teleprinter, already rotating, will signal back its call sign to indicate that the correct station "D" has been reached. "A" will then transmit the message and at the conclusion will depress the "Who are you?" key and automatically get the reply "D," indicating that the line has been through to "D" and its teleprinter during the transmission.

It is hoped that if the experiment is successful a description of this third phase will follow in another paper.

Mr. C. J. Mercer: The methods described in this paper appear to me to mark the end of an era in telegraphy—the era of d.c. telegraphy, which has lasted a century. It is just a hundred years since Morse took out his first telegraph patents. It is an era graced with names such as Kelvin, Morse, Wheatstone, Bain, Varley, Edison, and Baudot. The paper describes the manner in which the British telegraph service was converted from d.c. to a.c. transmission by the drastic method of scrapping all its apparatus except the teleprinter and disposing of all its line plant to another service. The new system was then built up by using voice-frequency apparatus and telephone lines in a combined telegraph and telephone network. These changes have resulted in a degree of economy, service, and flexibility in use, which was unapproached by the old method.

At the end of 1931 nothing seemed less likely than a wholesale voice-frequency conversion. Nobody with experience of the older systems of voice-frequency apparatus dared to visualize a comprehensive system such as that described by the authors. Further, at that time we were in process of reorganizing the telegraph service by installing new panel equipment on what was known as the Leeds system.* In December, 1931, however, the first circuit (London–Dundee) equipped with a new voice-frequency apparatus came into operation. It was an immediate and unqualified success, and it altered the whole outlook on the voice-frequency problem. We engineers in the telegraph branch, who had been inclined to put aside any idea of large-scale voice-frequency equipment, altered our views as the result of the improvements to be obtained from this equipment. The telephones were in need of lines, and it was subsequently agreed that the telephone branch should take over the whole of the telegraph network, thus leaving the way clear for a huge development of voice-frequency telegraphy. As to the economics of the change, the telegraph service was credited with something over £2 000 000 for the lines it handed over to the telephone service. The telephone service really got a good bargain, because they received all the benefits of accrued depreciation, but as many of these cables had been in use for 25 or 30 years I think we on the telegraph side were quite satisfied with our side of the bargain. The actual saving on the voice-frequency scheme, as it existed when the first big block of it was complete, and after we had had a year's working of that block, was between £130 000 and £140 000 a year.

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* *Journal I.E.E.*, 1933, vol. 72, p. 189.

* See R. P. Smith: *Journal I.E.E.*, 1933, vol. 72, p. 189.

The voice-frequency network possesses future possibilities and advantages which cannot at present be expressed in terms of money. The authors have touched on some of these, and I think the most important is the one which formed the subject of the demonstration, and which Sir George Lee has dealt with in some detail. An important point in this connection is that a through switching system is more likely to be successful if the traffic is evenly distributed than if it occurs in big blocks here and there, with sparse traffic areas in other places; the traffic returns which have been obtained appear to show that the traffic is in fact evenly distributed. The authors quote 4 to 5 minutes as the average time lost per channel with the voice-frequency system. Under the old d.c. regime we were never able to reduce the corresponding figure much below 40 minutes, in spite of much effort having been expended in that direction.

One result of the use of a joint telegraph-telephone network was the necessity for tightening up line-maintenance procedure, and, in the case of the telex service, to redesign certain items of telephone equipment. Small sources of trouble, unsuspected on the telephone system, but nevertheless prejudicial, were shown up clearly when a circuit was used for telegraphs. The advantages to be derived from a joint network are thus mutual, and technical as well as financial in relation to both services.

Mr. A. E. Thompson: This paper reveals that the most modern methods and the most modern mechanisms have been employed in remodelling the inland telegraph service. It also focuses attention on the valuable service which the C.C.I.T. is doing in defining the technical conditions to be met in providing the most efficient and dependable telegraph service over international lines.

During the past few years there have been striking improvements in the telegraph practice of the British Post Office, and it may be said with justice that these improvements have been made possible by the introduction of the teleprinter and the voice-frequency carrier telegraph system. The teleprinter has practically doubled the traffic output of the operators, and by removing the need for telegraphic skill it has opened up a much wider field of operations, while the voice-frequency system has enabled the telegraph to obtain the maximum benefit from its inherent economy in the use of frequency band width.

Looking to the future, the authors indicate that the next advance will be the introduction of through automatic switching between the office of origin and the office of destination. This will undoubtedly achieve a great simplification in method, and by eliminating retransmissions it will raise the standard of accuracy to a higher level and secure substantial savings in operating costs. It seems doubtful, however, whether these economies alone will be sufficient to turn the telegraph service into a revenue-earning concern. Would it not be possible to vitalize the service with a large volume of new traffic by connecting large commercial users to the nearest telegraph offices on the switching network, and so provide person-to-person teleprinter communication at rates considerably lower than for telephone service over corresponding distances, and more in line with the rates for the Tariff A private-wire services, which are growing so rapidly and bringing in so much additional revenue?

Referring to Figs. 8, 9, 10, and 11, it will be noticed that the results of the range of tests at 66 bauds (Fig. 10) do not conform with the results obtained at the lower and higher speeds. The increase in distortion involved in adding from two to six links is very small indeed. Does this not indicate that there is an optimum speed of working; and, if so, is it not possible to adjust the channel conditions to suit the standardized teleprinter speed of 50 bauds?

Mr. F. E. Nancarrow: This is, I believe, the first time that the subject of telegraphy has been brought before The Institution in the garb of a science rather than an art. In order to complete their record of present telegraph practice, I would suggest that the authors include in the final record of the paper some mention of the "ancillary" method of telegraph operation which has been introduced into the main telegraph centres of this country during the present year. I would also suggest that it might be more convenient if the authors modified their references to the *Avis* of the C.C.I.T. so as to bring them into conformity with the rationalized numbering scheme which was agreed upon at the recent C.C.I.T. meeting at Warsaw.*

I am interested to note that the authors emphasize the private-wire telegraph services, which in the next decade in this country will doubtless approach, if not exceed, in magnitude the public telegraph services. There is no doubt as to the demand which at present exists for the rapid transference of written matter from one place to another, e.g. between head offices of industrial concerns and their works or branches, and I am quite sure that this demand will grow as time goes on. Full account is being taken of this demand for private teleprinter communication in all the development work which is going on at the present moment.

Mr. A. J. Aldridge: There are two points which appear to me to stand out in this paper. The first is the fact that it has been shown to be possible to make the radical change-over to teleprinters and to the voice-frequency system, throughout a whole country, without interference with normal working. This change has been effected with remarkable speed and efficiency.

The second point is the evidence that has been given that telegraph transmission is now becoming a science rather than an art. Instead of trial-and-error methods of adjustment it is now possible to make accurate transmission measurements of the links in a telegraphic chain, and to be reasonably certain of the result when the links are coupled up.

Modern inland telegraphy is becoming more and more like telephony. In fact, the line problems of the two are practically the same, and it is only in the terminating links and instruments that the differences appear. In telephony it has been realized for some time that the old standard of transmission comparison, by volume alone, was inadequate, and attention has been drawn more and more to questions of quality, and elimination of disturbance. The distortion testers described in the paper are instruments designed to measure quantitatively what is, in effect, the telegraphic equivalent of telephone articulation, so that telegraphy has advanced in one step from practically no standard to a first-class standard.

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* This has since been done for the *Journal*.

These testers will measure the signal distortion to within 1 or 2 per cent, and the importance of this in design and maintenance need not be stressed. Of the two testers described, one, that used on the voice-frequency system, gives a kind of average distortion, while the other measures the individual distortion of each signal element. Perhaps the authors could give a little more information on the relative advantages of the two schemes.

The authors make a few comments on the relative merits of the telex system as used here, where transmission occurs over the normal telephone network, and the teleprinter exchange system, working over its own circuits. There are many technical difficulties to be overcome in telex working. The equipment is installed at the subscriber's office and must function without adjustment over lines of from 0 to 30 db attenuation, of all types, with and without echo-suppressors, and despite all the possibilities of trouble from the telephone exchange equipment. These difficulties have, however, been overcome, and on the face of it it would appear that the telex system employed in this country should be the more economical. On the other hand, in America, I believe, the teleprinter exchange system has been adopted, presumably for good reason. Can the authors state why the two countries have adopted different systems?

In Fig. 5 the authors show how faults and fault costs have gone down since the introduction of the voice-frequency system. This is due partly to greater experience obtained with time, and partly no doubt to the special training now given to the men. At the central training school at Dollis Hill, five courses are given covering telegraph working. These vary in length from 2 to 6 weeks each, and, in all, about 450 men are trained yearly.

Mr. V. J. Terry: Reading through the section on distortion (page 241), one cannot help regretting the clumsy nomenclature of the C.C.I.T. The "characteristic instant of modulation" needs at least a nickname. "Signal" is perhaps the best one we can find for it, and this has long been used to denote both the "characteristic instant" itself and the transient events which surround it. It is a pity, therefore, that the authors use the word "signal" to indicate the combination of "characteristic instants of modulation" which go to make up a letter, or, as I prefer to call it, a "character." No one, except perhaps musicians, will quarrel if we abbreviate "elements of modulation" to "intervals." A neat expression is still needed for the "time unit." I would suggest "chronon" for this, but not without a fear that I am stealing a term which physicists will need if it turns out that time passes in minute, but finite, periods, corresponding to quanta of energy.

On the other hand, I cannot agree with the implication [contained in Section (2)(*c*) of the paper] that the C.C.I.T. definition of distortion would be of more direct practical application if modified to make allowance for the special circumstances surrounding the all-important start signal.

In teleprinter practice, a minimum stop interval of $1\frac{1}{2}$ "chronons" is not universal. In places where the 7-unit code is used the maximum distortion is liable to fall both on the start signal and on another signal in the same character, and a distortion-measuring set which distinguishes between the start and other signals will therefore give the same maximum distortion as one working in accordance with the present definition, but only if the observations are continued for a sufficiently long period. The present definition gives the quickest and most accurate measure of telegraph quality in the general case.

A paper recently published elsewhere* puts forward the theory (based on the laws of probability) that in a telegraph channel consisting of a number of links connected in tandem, the probable maximum distortion should be equal to the square root of the sum of the squares of the maximum distortions of the links measured separately. This theory applied to the author's measurements, which are recorded in Figs. 8, 9, 10, and 11, would make the probable maximum distortion of a tandem connection proportional to the square root of the number of links, but in practice the relationship between the number of links and the maximum distortion is almost linear. The explanation may perhaps be found in the fact that when a large number of links are connected together the signals passing through the last few links are so distorted that the minimum interval is substantially less than 1 "chronon," and the speed of working (which is the reciprocal of the minimum interval) is effectively increased, possibly near to the point at which the link is liable to fail. This is likely to produce a further large increase of distortion in the links affected, so that the maximum distortion of the tandem combination increases more rapidly, with the addition of further links, than would be anticipated from a theory which assumes that the distortion in each link is independent of the number connected together. It would appear, however, to be a mere accident that this effect should so modify the result as to make the relationship approximately linear. To determine with accuracy what law the additions of distortion follow, a larger volume of data is really required. It is therefore to be hoped that telegraph engineers will make a common pool of suitable measurements in order that this important problem may be solved.

Except in submarine cable practice, regenerative repeaters do not appear to be used extensively, in spite of the almost magical property which enables them to restore to virtual perfection signals distorted by random, as well as systematic, errors. It would be interesting to know how many are actually used on landlines in the British Isles and whether the authors consider that future improvements in telegraph transmission are likely to keep pace with the growth of tandem connections, so that satisfactory overall transmission will continue to be possible without regeneration in all but a few special cases.

In Section (4) (*c*) (i) an explanation is given of the distortion arising from half-wave rectification, together with figures for the magnitude of this effect. This explanation and these figures are given in reference to cases where a wide band of frequencies is transmitted so that the envelope of the voice-frequency currents is almost " square." They do not apply, however, when only a narrow band of frequencies is transmitted, and the build-up and decay of the voice-frequency currents take several whole cycles of the carrier wave. In this case the distortion due to half-wave rectification may be very much smaller, and may even be reduced to the point where it is comparable with the less-known distortion produced in narrow-band channels, by modulating the carrier current by " square " signals. For the half-wave detection of voice-frequency signals, some form of smoothing circuit is essential after the rectifier. This may take the form of a condenser shunting the inductive winding of the receiving relay, or it may be the mechanical inertia of the armature itself. In any case it is desirable that the constants of this circuit should be such that the final output of the detector, whether it be a current or the movement of an armature, does not contain appreciable components of the carrier frequency. It should, however, transmit efficiently, and without serious phase distortion, currents or movements at all frequencies up to, and a little beyond, one half of the effective band width of the voice-frequency transmission path, when a linear rectifier is used. When a square-law half-wave rectifier is employed, about double the frequency range should be transmitted by the smoothing circuit. With such a smoothing circuit, a linear half-wave rectifier gives an output which is a delayed and diminished replica of the envelope of the voice-frequency input current, and the form of the smoothed rectifier current is independent of the phase of the voice-frequency current in relation to the signal (" characteristic instant of modulation "). Fig. A illustrates this point. The final amplitude of the smoothed rectified current with an ideal half-wave rectifier is equal to the peak amplitude of the steady carrier current multiplied by $1/\pi$. If allowance is made for the time-delay in the smoothing circuit, and if the amplitude of the wave to be rectified is not varying rapidly, it is fairly accurate to assume that, at the moment in each cycle when the unsmoothed current attains its maximum value, the ratio of the unsmoothed current to the smoothed current is $1/\pi$. The continuous thin line in Fig. A shows the build-up of voice-frequency current in a typical narrow-band channel in response to a positive signal. The heavy line shows the corresponding smoothed rectified current, and the crosses mark values equal to the peak amplitudes of the positive half-cycles multiplied by $1/\pi$. The heavy dotted line represents the smoothed rectified current displaced in the time scale so as to pass through the crosses. If the phase of the voice-frequency wave is reversed, as shown by the thin dotted line, the smoothed-current curve (displaced) still passes through points (marked by circles) which denote the peak values of the unsmoothed current multiplied by $1/\pi$. The same is true for all phases of the voice-frequency wave in relation to the signal. By reversing the time scale and displacing the rectified-current curve to the left, Fig. A can be made to give also the decay of current representing a negative " signal," and it will thus be seen that the phases of the carrier wave at the signal instants need occasion no displacement of one signal with reference to another when half-wave rectification is employed. It is, however, easier to provide the necessary smoothing and to approximate to the ideal conditions when using full-wave instead of half-wave rectification.

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* R. E. Pierce and E. W. Bemis: "A Transmission System for Teletypewriter Exchange Service," *Transactions of the American I.E.E.*, 1936, vol. 55, p. 961.

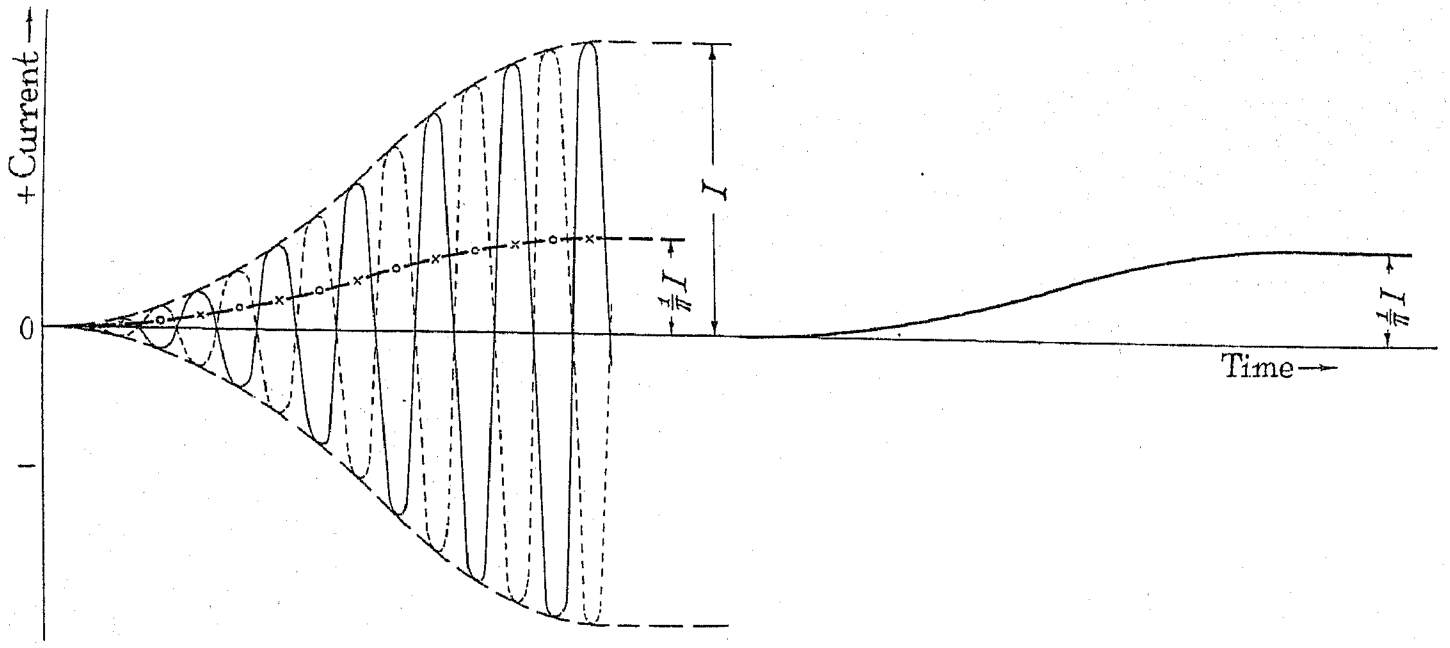
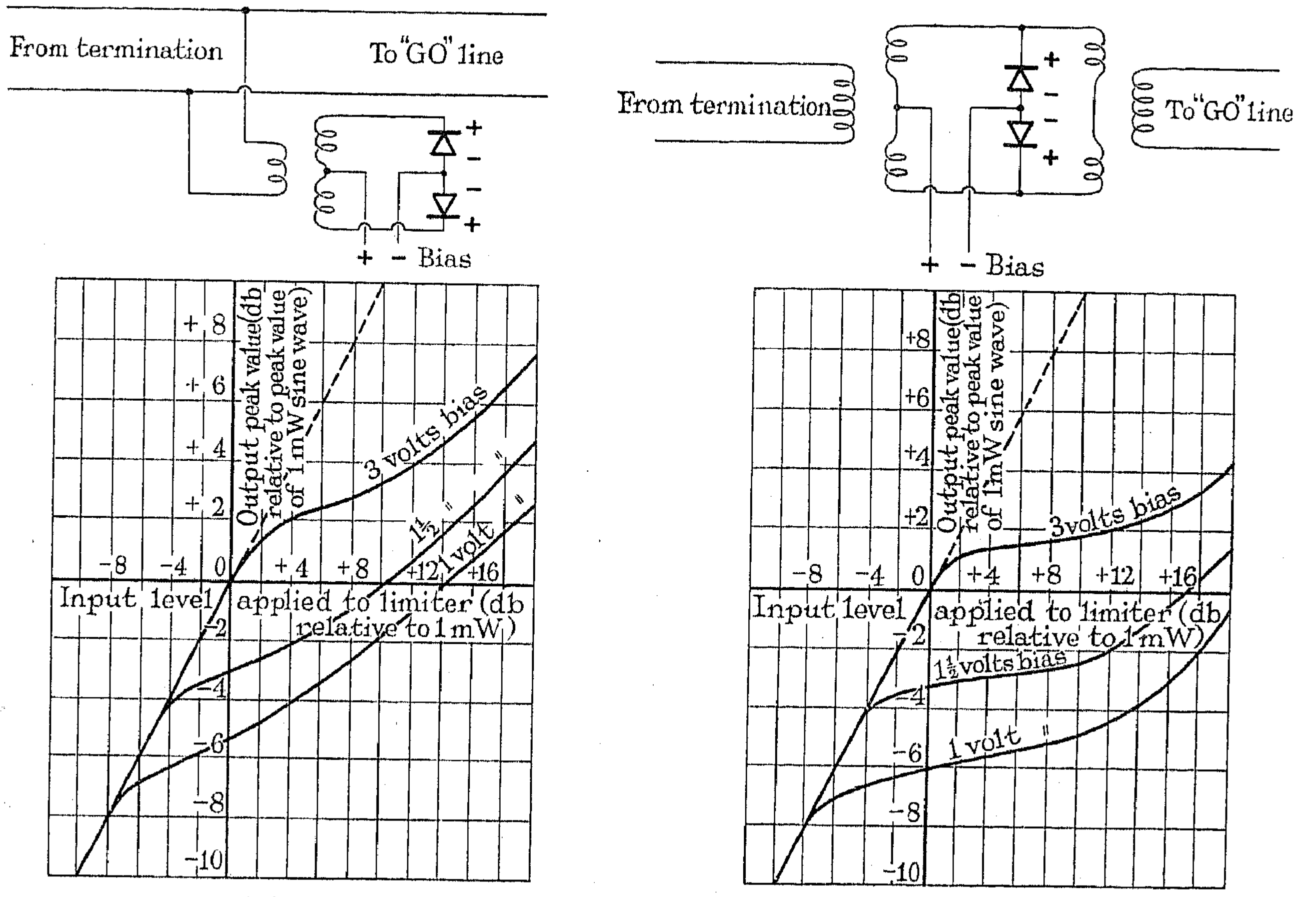


Fig. A

— — — — Envelope.
———— Voice-frequency current in observe phase.
- - - - - - - - - Voice-frequency current in reverse phase.
× × × × $\frac{1}{\pi}\times$ (Peak values of positive half-cycles of voice-frequency current in obverse phase).
○ ○ ○ ○ $\frac{1}{\pi}\times$ (Peak values of positive half-cycles of voice-frequency current in reverse phase).
━━━━ Smoothed rectified current.
━ ━ ━ Smoothed rectified current displaced in the time scale.

Mr. R. O. Carter: On pages 251 and 252 [Section (3) (*k*)] of the paper the authors refer to an experimental 8-channel super-audio telegraph system working between

London and Newcastle. Some account of recent experimental work on this system may be of interest. The carrier terminal equipment is the same as is used on the standard Post Office "one plus one" carrier system, which normally operates over a circuit having 22-mH loading, and then gives one complete telephone carrier channel in addition to the audio channel. In the present case the loading is 44 mH, and the useful frequency range extends up to about 4 300 cycles per sec., so that the carrier channel is too narrow for speech but wide enough for a number of telegraph channels. To avoid confusion, it may be called a "one plus a half" carrier system.



(*a*) (*b*)

Fig. B

(*a*) "Bridged" type limiter.
(*b*) "Transmission" type limiter.

Tests have been carried out to see whether it is possible to obtain the same high grade of performance on these telegraph channels as is obtained with the 18-channel system operating on a plain voice-frequency circuit. Two causes of telegraph distortion have to be investigated:—

(1) *Spacing interference.* This is caused by non-linearity in the repeater-valve characteristics and in the loading coils. Some of the products of intermodulation of the various frequencies being transmitted will fall within the band-width of any particular telegraph channel, where they will cause distortion of the received signal. In the case of a normal 18-channel system, tests on a number of working systems have shown that the level of this interference reaches peak values of about 18 to 21 db below the desired signal. In the "One plus a half" system, spacing interference arises not only from the intermodulation of frequencies transmitted on the other telegraph channels, but also on account of speech on the audio telephone channel. Working levels have to be selected so that the total interference is no worse than that obtained on the normal 18-channel systems. In measuring the signal/interference ratio, it has been found convenient to employ a cathode-ray oscillograph as a peak voltmeter, by connecting it, via a suitable amplifier, to the output of the receiving filter of the telegraph channel under test. This method is of particular advantage when measuring interference arising from speech, as the peaks of interference occur only occasionally.

(2) *Marking interference.* This arises from the change of overall gain of the trunk circuit with the power level transmitted, and is also caused by non-linearity in the valves and loading coils. The result is that the level of received signal on any telegraph channel is different, when other frequencies are also being transmitted over the circuit, from the level when no other frequencies are transmitted. On normal 18-channel systems the change is less than 1 db. If we attempt to work the super-audio system at the same transmitted level per channel, the marking interference is worse, owing to the fact that the effect on the circuit attenuation of a given change of inductance or effective resistance of the loading coils is greater at frequencies close to cut-off than at lower frequencies.

In order to reduce these two types of interference in this 8-channel system the possibility has been investigated of limiting the maximum speech voltage transmitted on the voice channel to a lower value than on the "one plus one" carrier system. Fig. B shows the type of limiter normally fitted, and also a modified type. The first consists of a transformer bridged across the line, to the secondary winding of which a pair of copper-oxide rectifiers are connected, a bias voltage being applied. When the speech voltage developed across the rectifiers exceeds the bias voltage, the rectifiers conduct, and the impedance bridged across the line drops to a low value, thus reducing the peak voltage transmitted. In this arrangement the limiting action is reduced by the resistance of the windings and by the leakage inductance of the transformer, as the impedance cannot fall below the primary impedance with the secondary winding short-circuited. In the modified circuit the deleterious effect of the resistance and leakage inductance is eliminated by the addition of a second transformer, the whole arrangement being inserted in the transmission path instead of as a bridge. The limiting action depends then only on the resistance of the rectifiers in the conducting direction. The curves relating the input level (i.e. the level which would exist if no limiter were inserted) to the output peak value for each type, show the improvement obtained. The "bridged" type is, of course, simpler, and is perfectly satisfactory for the purpose for which it was designed.

By reducing the bias voltage to 1·5 volts (the normal value is 3 volts) and adopting the modified circuit, an improvement in limiting at high levels of about 6 db is obtained. This in turn reduces the spacing interference arising from speech on the voice channel by about 12 db. Tests show that the articulation is unaffected.

In conclusion, though it appears probable that, with careful selection of working levels, a performance equal to that of the normal 18-channel systems will be obtainable, it is considered that the ideal solution would be the provision of repeaters employing negative feedback, which would eliminate, for all practical purposes, the intermodulation in the repeaters and leave only that in the loading coils.

Mr. E. S. Ritter: On page 243 the authors say: "The value fixed by the C.C.I.T. for practical purposes is 35 per cent." Further, on page 247, they say: "The C.C.I.T. has laid down that the total distortion of a telegraph circuit must not exceed 28 per cent and that the distortion of each link in the circuit should not exceed 10 per cent when measured as a separate circuit." If, say, 5 per cent distortion is added for the variation of distortion in the transmitter, which leaves a distortion of 33 per cent, 35 per cent margin is specified for the receiving instrument; is the 2 per cent margin of variation sufficient for reliable operation?

Another point which I want to bring out is this: At present two teleprinters working together on a circuit may, if required, be adjusted in speed to a difference of $\frac{1}{2}$ per cent. The speeds are adjusted to a standard of $\pm\frac{1}{2}$ per cent, but if one has a number of machines such as work together on switched connections the possible variation of speed is twice the tolerance, i.e. there is a possible difference of speed of 1 per cent; so that the closer one can set speed to a standard the better the operating margin. Now, in connection with switched connections, the point I wish to make is that at the receiving end, owing to there being chance traffic, more receiving machines than senders are required on any given circuit, and when the switching system comes into operation it may therefore be desirable to have teleprinters without keyboards, as they will only be required for receiving purposes.

As telephone engineers have shown telegraph engineers how to work their system by the multi-channel and other voice-frequency methods, perhaps telephone engineers in future will learn from the telegraph engineer how to send distortionless dialling pulses over the telephone network.

Mr. W. F. Bevis: From Table 4 it appears that the inductance values for the sending shunt have each been measured at a nominal current value. In recent experiments, using this method of transmission, it became apparent that a knowledge of the variation of the inductance with the changes in current values is required to obtain the optimum transmission. Since there is a rapid rise and fall in sending current owing to the transient surge into the cable, it has been found that coils in which the inductance decreases with an increase in current—brought about by the saturation of the core—may be used to advantage. In the recent experiments referred to, use has been made of the saturation effect of the core, and this actually brings about improved transmission. From a practical aspect this is very valuable, because not only is transmission improved but the physical dimensions of the coil may be considerably reduced.

Mr. H. H. Harrison: It would be extremely interesting if a diagrammatic comparison could be made between the network shown in Fig. 6 and the same network employing, as would formerly have been necessary, the forked repeater. The difference between the linking arrangements that would have had to be used in the old days (even if such a network as that of Fig. 6 had been possible) and the combiner arrangement of Fig. 7, is very striking.

Mr. Nancarrow and Mr. Aldridge referred to the fact that telegraph transmission is now developing on a scientific basis. In the early days the only data on inland transmission that were available were a few curves connecting telegraph speeds and length of line. Curves representing the reciprocal values of *CR* and line length were slid up and down vertically until they fitted the observed results sufficiently satisfactorily. These results could not be applied to composite circuits; and, moreover, the tolerance was much too great owing to the fact that the receiver was a human being with a brain, and if there was a tendency for dots to drop or dashes to run together the record strip could still be interpreted. With the machine, however, this discriminatory function does not exist, and if a signal does not possess reasonably good quality a wrong letter is recorded. The machine itself adds sources of signal distortion in excess of those inherent in the older, simpler, apparatus.

I should like to confirm the utility of the distortion-measuring set described in Figs. 30 and 31. Almost as soon as this apparatus appeared my company constructed a rough model of it for use in connection with a regenerative repeater we were making, and the amount of information we were able to obtain by this means as to the performance of various details of the repeater was really extraordinary.

In conclusion, I should like to suggest to the authors that they make certain additions to the Bibliography.*

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* This has been done for the *Journal* [Items (44), (45), and (46), on page 268.

Mr. T. W. Leek (*communicated*): In Section (7) I think the authors could, with advantage, have amplified their observations and given a more definite indication of how it is proposed to adapt the inland telegraph service to the conditions of automatic telephony. Presumably the scheme is intended to operate on a national basis, each individual operator being in a position to dial direct to the delivery office in any other part of the country. Is this operation to be performed over the existing voice-frequency network plus physical extensions, or will it entail the linking of voice-frequency channels to the trunk telephone system? I think it will require a large increase in both voice-frequency facilities and physical extensions.

The economic value of the proposed scheme seems to me to lie between operating costs and line and apparatus costs. There would no doubt be considerable saving in operating charges at the present intermediate points, though this would, to some extent, be offset by increased charges at the originating offices unless some special precautions were taken to provide for "engaged" conditions and checking of operator output. The apparatus required would be expensive, taking into account the number of variations to be allowed for—such as distribution, calling, completion of connection, clearing, and engaged signals, etc. Additional line costs, though considerable, would, taking into consideration the extensive voice-frequency network already existing, form not too great a proportion of the total expenditure.

As regards supervising of operator output, I have in mind the conditions existing on the present telephone, telegram, typewriter system, which is, in some respects, analogous to the proposed scheme. My own experience of the former has led me to the conclusion that considerable operator time and line time are avoidably lost by the difficulty of supervising each call from its inception to its termination; and unless some special precautions are taken to deal with this aspect in the new system, I am afraid it will lend itself to an extension of these undesirable features.

One other question I should like to ask concerns the generation of the required frequencies. As I understand it, at present a frequency generator is required at both voice-frequency terminals on a system, and this generator can supply up to 18 channels. Traffic at many of the smaller stations will only be sufficient to warrant the provision of one or two physical extensions to the main voice-frequency network. If a system could be devised whereby the frequencies for both go and return lines could be generated at the main office, the out-stations would be independent of local supplies and the 18 channels could be divided between a number of them, eliminating the physical extensions. This, I think, would result in greater flexibility and would have the advantage of bringing practically every station on to the voice-frequency system. I should like to know whether anything of this nature has yet been attempted.

Dr. L. E. Ryall (*communicated*): The authors are no doubt familiar with the echo-suppressor shown in Fig. 20 because of the transmission problems associated with it in conjunction with telex working. Even with the modification indicated, satisfactory operation cannot be obtained unless the transmission time of the circuit from the suppressor station to the receiving terminal and return is of the order of 4 to 5 milliseconds. This type of echo-suppressor has now been superseded for all new installations in Great Britain by the differential echo-suppressor.* Because of the differential feature its operation is entirely satisfactory even when the suppressor is located at the terminal station, and its presence on circuits used for telex cannot adversely affect the telex operation.

[The authors' reply to this discussion will be found on page 282.]

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* B. S. Cohen: "Research in the British Post Office," *Journal I.E.E.*, 1934, vol. 75, p. 145.

NORTH-EASTERN CENTRE, AT NEWCASTLE, 9TH NOVEMBER, 1936

Mr. William F. Smith: Telegraphy and telephony each has its own particular field of application to everyday life, but they are inseparable in the research laboratory. The rapid telephone development in recent years has been made possible, in large measure, by the development of voice-frequency transmission of telegrams, which has enabled many of the old telegraph cables to be made available for telephone purposes after reconditioning. At the same time the provision of telegraph channels on the voice-frequency principle has made possible, economically, a far larger network of communication "lines," as is indicated in Fig. 2.

I am a little disappointed that more reference is not made in the paper to the problem of telex versus tariff A. The scope of telex, which provides both telephone and telegraph facilities, seems almost unlimited, its popularity increasing with the number of such subscribers. There appears to be no advantage in the tariff A system except that of cost, and it would appear better to facilitate the development of telex by reduction of charges so that the need for tariff A service is removed.

It is stated that in the telegraph broadcast system the number of out-stations that can be communicated with simultaneously is limited by the number of teleprinters installed at the central office. This is not clear, since the feature of the system is that one message can be simultaneously received at a number of points and only one machine would be necessary at the central office. The limit to the number of out-stations would seem to be fixed by the transmission qualities of the lines connecting to the central office.

It is interesting to note the marked reduction in apparatus faults, and particularly the improvement attained by the change to copper-iridium contacts on the receiving relays. The curve of Fig. 5 showing the maintenance cost presumably includes routine maintenance as well as fault maintenance. The reduction in the total maintenance figure would probably be accounted for more by the increased number of units installed which could be attended to without increasing the maintenance staff, than by the improvements effected in apparatus design.

Referring to Fig. 12 and Table 2, it can be appreciated that the distortion may not be proportional to the length of line, but it is not clear why the distortion should in some cases increase with distance and in others decrease.

Mr. T. Jordan: On page 240 of the paper, it is stated: "Cable companies, news agencies, and newspapers, make considerable use of duplex point-to-point circuits for speeds up to 100 words per minute Wheatstone, or the equivalent." I suggest that these circuits should be described as 2-line simplex circuits rather than as duplex. Referring to the speed in words per minute, it is known that a local renter has obtained and worked a speed of 125 words per minute on the voice-frequency system, which, converted to bauds, is approximately 100. Seeing that the system was designed for 66 bauds, this example shows the wide margin obtainable.

On page 245 the authors quote the average time taken for a change of system as being 8 minutes. I think this figure is rather high, more especially in view of the fact that a report is called for if a stoppage on any system lasts for more than 5 minutes.

Among the benefits resulting from recent developments perhaps the greatest from the engineering point of view is standardization, and the removal to a large extent of the human element both from the maintenance side and from the telegraphic side. With regard to the efficiency of the teleprinters, from experience of some of the earliest circuits I can say that very great progress has been made. Originally the method of testing the speeds of teleprinters was by stroboscope; when it was required to know whether the distant machine was correctly adjusted for speed, the answer usually received was "I can see nothing but a white ring." By the introduction of such pieces of apparatus as the synchroscope, these "persistencies of vision" are avoided and, in consequence, slight variations of the general conditions have not the same effect upon the working of the circuits.

Mr. J. A. Stanfield: On page 240 the authors speak of tariff A circuits as "simplex"; I suggest that they are still "half-duplex." Regarding the sharp decrease in channel faults coinciding with the change from platinum-iridium to copper-palladium contacts on receiving relays, it will be observed that about the same time the rate of installation of equipment had slowed down considerably, bringing with it a more or less settled state of maintenance and routining in the repeater stations. It is in my opinion more likely that this return to normal conditions was more responsible for the reduction in the number of faults than the change of relay contact metal. It would seem that the contacts still "pit" and "hill" considerably, and that the transfer of metal has reversed itself with change of contact material; that is, whereas with platinum iridium there was a build-up on the marking contact, now we get a build-up on the spacing contact.

The distortion figures on page 250 are very interesting, but I suggest they be made round figures, in view of the fact that distortion readings on the normal telegraph distortion measuring set cannot be read to greater accuracy than 2 per cent.

As the speed on a voice-frequency channel is increased, the received signals tend to become more biased to "mark," until a point is reached when this effect cannot be compensated for by bias adjustment. Is this due to transient effect?

It fills one with apprehension to see any mention of more than three voice-frequency links being connected together, and I hope it will never be necessary to have more than two voice-frequency links where high-speed circuits are concerned.

Mr. James Anderson (Newcastle): There is a method, I understand, of measuring the attenuation of the filters associated with the multi-channel voice-frequency equipment, by means of the carrier frequency of any particular channel (which may be obtained at the "carrier frequency test jacks") and the amplifier-detector and its associated potentiometer, the latter being calibrated in decibels. I shall be glad if the authors will describe this method.

The introduction of the multi-channel voice-frequency telegraph system marks a big step forward in the British Post Office telegraph system, as it means that 18 go and 18 return channels may be worked over a 4-wire repeatered cable circuit, thus making spare a number of wires in telegraph cables, which, after reconditioning, can be used for the setting-up of new telephone circuits. Further, in the case of a breakdown in the 4-wire telegraph system, it is the work of a few moments to transfer the circuit to another 4-wire line, thereby causing very little delay in the transmission of messages; also, in the case of a complete cable breakdown, an alternative route may be chosen.

Formerly, owing to the large capacitance of underground cables, very long telegraph circuits were usually worked over aerial lines. The introduction of the new system of telegraph signalling, together with the use of loading coils, now permits these aerial circuits to be worked in underground cables. This has enabled the Post Office to transfer main telegraph circuits from aerial lines to underground cables. This is a decided advantage, both from an economic maintenance point of view and on account of the fact that underground cables are relatively immune from the effects of storms.

[The authors' reply to this discussion will be found on page 282.]

NORTH MIDLAND CENTRE, AT LEEDS, 10TH NOVEMBER, 1936

Mr. W. R. Tyson: The fact that The Institution was formerly The Society of Telegraph Engineers suggests that during the early days its discussions were mainly concerned with telegraphs and telegraph development. Some years later, the phenomenal development of the heavy side of the electrical industry naturally resulted in telegraph interests being pushed into the background, where they lay, more or less moribund, for half a century or more. Since the War, however, there has been a great reaction; the thermionic valve has revolutionized transmission methods, while operating practice has been completely reorganized by the introduction of the teleprinter, and once again interest in telegraphic matters is well to the fore.

In reading the paper one is rather struck with the emphasis placed on distortion, the need for eliminating it, and the steps taken to effect that elimination. Now telegraphic communication may be reduced, more or less, to the transmission of rectangular wave-forms, and one is rather inclined at the outset to wonder why in telegraphic communication involving a moderately simple wave-form it is so necessary to pay attention to the need for overcoming any distortion that may occur. The amount of distortion that can occur to a rectangular-wave-form transmission is nothing like as much as occurs with the very involved waves of telephonic practice. Clearly, the two parties in telephonic communication consist of an individual speaking and an individual listening, whereas the two parties to a telegraphic communication consist of an instrument sending and an instrument receiving. The instrument sending can be likened to the individual speaking; the instrument receiving can be likened to the individual listening. Now the human hearing system can put up with a great deal of distortion before losing the ability to translate the received signals into correct intelligence; and this ability discounts, to a large extent, any distortion occurring on the line. On the other hand, any attempt to reproduce mechanically the hearing functions of the human brain, as in teleprinter working, can meet with only very limited success. The machine cannot automatically fill in the gaps and make good the distortions as the human brain can do, and it is therefore necessary to take care of the purity of wave-form during a telegraphic transmission. The machine must receive perfect or nearly perfect signals before it can perform its work with accuracy.

I am very interested in the rectifier type of modulator; this instrument must result in quite a large saving in capital cost as well as a considerable saving in maintenance costs. It is essentially static. There is nothing that can go wrong with it, provided the transmitted current is kept in proper limits.

I am also interested in the noise discriminator; can this eliminate such types of noise as are superimposed on the line by microphonic contact between the wipers and bank of an automatic switch?

On page 242 the authors give the opinion that overall costs can be reduced by providing much more complicated equipment, with a consequent saving in operating costs. Highly complicated equipment necessitates the provision of highly technical and very able maintenance staff, however, and there must be some limit beyond which it ceases to be economic to complicate the working equipment. The present maintenance staff are paid about the same amount as the operating staff, but the work of the former is being rendered increasingly more difficult, and of the latter, more simple. We shall not get the right type of individual to maintain these increasingly intricate services without giving him more money and more attractive prospects. I should like some information as to the economic point to which it is possible to increase the expenditure on capital and maintenance of engineering plant in order to decrease operating costs.

I should like to express some measure of disappointment that the future of the telegraph service is relegated in Section (7) to half a column on "Trend of Development." We know that very soon we are going to be faced with automatic telegraphy, which will be in effect the grafting of teleprinter working on to the automatic telephone system not as a local but as a national system. My remarks with regard to the complication of plant apply also to the development of automatic telegraphy.

Mr. C. J. Jones: It will be generally agreed that the static relay has removed a considerable amount of trouble from a maintenance point of view, and, as there are no contacts in it to be kept clean, a reduction in maintenance costs is thereby effected.

It may be of interest to know that at the Leeds Post Office approximately 18 000 telegrams are transmitted each day in the winter, and 25 000 in the summer, rising at times to a peak load of 36 000 telegrams per day; and, in addition, at least 5 000 messages are transmitted daily by means of phonogram lines. When the cheaper rate came into force this increased the number of messages by 27·5 per cent in the summer and 80 per cent in the winter. We have provided a telegraphic system in which delay is almost negligible, and in the event of a breakdown of a system a complete change-over can be effected to a spare circuit in a few minutes.

Mr. J. F. Murray: The question whether the telegraph service will pay is a very big one. There has been great competition for many years between the telephone and telegraph systems. Part of the recent improvement in the outlook of the telegraph service is due to the provision of the vast network of voice-frequency circuits described in the present paper, and this development has enabled the telegraph service to be put on a different footing from that of a few years ago.

Reference is made in the paper to the 35 per cent increase in telegraph traffic after the rates had been reduced, and it should be added that in Leeds this summer the figure rose to 50 per cent. The figures of telegraph traffic are still rising all over the country. Of course, if one reduces the rate from 1s. to 6d. and in consequence gets a 50 per cent increase in traffic, one cannot say one is making ends meet; but the financial gap is narrowing, and a time will come when that gap will disappear altogether.

As regards future developments, the principles of the automatic telephone switching systems are likely to be applied to the telegraph network, and the transmission of telegrams in the future will therefore differ in many essentials from present practice.

I agree with the authors that the numerous tariff A circuits which have been set up between business houses all over the country have diverted traffic from the telegraph service; but there have been compensating financial advantages to the Post Office. An interesting side-light on this question came to my notice some time ago when the secretary of an important firm said to me: "You are offering us a tariff A teleprinter service to London at £400 a year, but we pay you £500 a year for telegrams. There must be a snag somewhere." I assured him that there was not, and went on to explain that every telegram his firm passed into the Post Office was on the average transmitted by three operators before it got to its destination, that we would be able to save the time of these three operators, and that we were going to save certain line and apparatus costs as well.

Mr. S. A. F. Adam: It is stated by the authors that a certain amount of bias may occur owing to the fact that when a space is transmitted (i.e. the tone is short-circuited) there may be a high-resistance contact between the tongue and spacing contact of the send relay. Some tone will consequently be transmitted to line, this of course being the reverse of what is required. It seems to me that this could be obviated if the tone, instead of being short-circuited, were to be open-circuited. The effect would be identical, no tone going out to line for a space. If a high-resistance contact did develop, the net result would merely be the transmitting of mark tone at a lower decibel level, and, seeing that this is automatically compensated for within limits of ± 8 db by the receiving valves, it would not seem to matter very much.

Another point which strikes me concerns the authors' use of the word "carrier." Normally we mean by a carrier a high-frequency current modulated by a low-frequency current, this latter being, say, the voice. In telegraphy, however, we have a low-frequency current which we either transmit to line (to represent a mark) or do not transmit (to represent a space). I should like to know whether the authors consider that this is really a carrier type of current or whether they only call it so for want of a better word.

Mr. A. K. Robinson: One thing which the paper makes evident is the revolutionary nature of the change which has taken place in telegraphy, not only on the technical side but also in the outlook. A notable feature is the rapidity with which the change has taken place.

I am surprised to find on page 240 the words "with the teleprinter as a mere accessory of the telephone." Those of us who use the telex service daily find it almost invaluable. Telegraphy has a place in communications which the telephone can never take: it is independent of the individual, and independent of time, inasmuch as one is not dependent on being able to obtain the person desired just when one rings. I think that tariff A, tariff D, and telex, are amongst the most useful facilities ever offered to the public.

I am rather curious about the footnote on page 241, which refers to systems where frequency and not time is the basis of discrimination. I should like to know whether this footnote foreshadows some further development in telegraphy of which we have not yet been informed.

There are three technical points I should like to refer to. First, I am interested in the matter of double modulation in connection with the use of frequencies outside the audio range, and I was surprised at the implication that the requirements of telegraphy are more stringent than those of telephony, as regards frequency adjustment of the carrier system. The 6 cycles per sec. variation permissible in the telegraph frequencies means a loss or gain of approximately one-third of a semi-tone in the whole of the commercial audio-frequency range. A piano tuner is, I believe, expected to be able to tune to 1/50th of a semi-tone, but I presume that most of us are not musical enough to appreciate the 6 cycles per sec. difference referred to. I assume that the difficulties in connection with frequency maintenance mean that we are not likely to have telegraph carriers working on the ultra-high frequencies which we are now expecting to use for telephone channels: 6 cycles per sec. in a million is a fairly high degree of accuracy for practical conditions.

Secondly, the effect of using the odd multiples of 60 for carrier frequencies in order to avoid second-harmonic trouble is to bring the third harmonics exactly into line with other carrier frequencies. Have the authors any information as to the prevalence of third harmonics? Is the absence of trouble entirely due to the low level at which these telegraphs are worked, or are there other reasons?

The third point is in connection with the level; the authors take an arbitrary level of 10 microwatts per channel, and I should like to know whether they can tell us the fundamental basis of the C.C.I. limit. It appears to be arrived at by dividing an arbitrary figure by the square of the number of channels, and I am not at all sure how this basis has been decided.

Mr. G. K. Hall: One of the developments that impresses me in particular is the telex convertor, which seems to me to get over some of the major difficulties in connection with the telex service. I do not know whether everyone realizes the advantage of a telex system in that a local record is obtained. One of the troubles arising from interference with telex messages due to automatic switches was that a click gave a figure shift which made all the letters turn to figures. This was rather unfortunate in a long message. It gives me great pleasure to see a convertor which is going to eliminate that trouble.

Another notable development is the changing of the tariff A service from d.c. working in the main to voice-frequency working, which the authors tell us is of such a high standard to-day.

[The authors' reply to this discussion will be found on page 282.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 1ST DECEMBER, 1936 *

Mr. Alfred Morris: A few years ago there were grave doubts whether telegraphs were going to flourish or to founder, but recently the technique of telephony has been so successfully applied to the sister art that the decline of the telegraph has been definitely arrested. The number of inland telegrams increased during the past year by 9 millions to a figure of 44½ millions, indicating a very healthy condition of the telegraph service. These results have been achieved because modern apparatus and ideas have been applied to the telegraph service. I refer particularly to the use of what is known as "by-product circuits," which consist of the phantom circuit in the case of the modern quad cable circuit—unsuitable for telephone purposes because of its large capacitance and the absence of loading—and of the double phantom or "ghost" circuit in multi-twin cables. Again, there is the application of the thermionic valve, both as a rectifier and as an amplifier, and the application of the copper-oxide rectifier. There is also the use of the electric filter, and the application of alternating current to the telegraph system. We have been told, and it cannot be too strongly emphasized, that the present telegraph service is based almost entirely upon the use of voice-frequency currents.

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* Joint meeting with the Institution of Post Office Electrical Engineers.

Dealing with the technical aspect, I suppose it is fair to say that the problem presented in this new kind of telegraphy is exactly the same as the problem presented in the telecommunications problem as a whole. It is necessary to convert intelligence which we want to pass from one location to another into some form of electrical signal, to transmit such electrical signals from one place to another over wires or through the ether, and then to receive them and reconvert them into intelligence. Different kinds of intelligence require frequency bands of differing widths for their effective transmission; thus for music and elocutionary speech a band width of about 5 000 cycles per sec. is needed, whilst a band as wide as 1 million cycles per sec. is essential for high-quality television. The band width reserved for a single telegraph channel is 120 cycles per sec., but, because the total band width available for transmission purposes over an ordinary cable circuit is of the order of 3 000 cycles per sec., a large number of telegraphic channels —18 in fact—can be operated at the same time over the same medium. One striking feature of the voice-frequency system is this multiple character and the fact that a large number of messages can be passed simultaneously, thereby utilizing the same material a large number of times.

The application of scientific methods to the telegraph service has enabled operating costs, which formerly were too heavy, to be reduced. The system has been so modified that the volume of traffic to be handled can be dealt with by a very much smaller number of operators. This point is a vital one so far as the development of the system is concerned.

Another point in regard to the width of the band necessary for effective working is that the higher the speed of transmission the wider is the band required. The present band width of 120 cycles per sec. is suitable for a speed of the order of 50 or 60 words per minute. If it is desired to transmit very many more words per minute in order to keep down these operating costs—quicker handling of traffic means reduced operating costs—it is necessary to widen the band; but if the band is widened the number of channels that can be utilized over a particular medium is correspondingly reduced. The future tendency will therefore be to utilize lines and circuits which have a very much wider transmitting band than is used at the present time.

On page 242 the use of the term "inefficient use of band width" is perhaps rather unhappy. If for the effective transmission of a certain kind of intelligence a certain width of band is necessary, I do not think we can accuse engineers of using band width inefficiently. The fact is that, if a wider band per telegraph channel is to be used, then certainly fewer channels can be operated over a given medium, but the wider band per channel is necessary because it gives a corresponding advantage from the operating point of view.

Another important point brought out in the paper is that of the co-operation which has been necessary, and which has resulted in such a successful development of the telegraph system. The authors give many references to the C.C.I.T., and it is very striking that so much co-operative work has been done in attacking the problem. The C.C.I.T. provides opportunities for the joint technical study of the problem, for actual experimental field work, and, most important, for co-operation between the various nations concerned in the problem. One of the authors is a member of the C.C.I.T., and it would be interesting to hear some of his experiences in that connection.

Mr. T. E. Herbert: The authors say that until we had the voice-frequency network a telegraph switching system was not practicable; and yet it is a fact that the U.S.A. have a system somewhat similar to our own telex, but worked on telegraph channels. I should like to emphasize the point that the teleprinter is a British instrument, and that the static relay and other important devices in telecommunication engineering making use of copper-oxide rectifiers have been due to the work of a number of British Post Office engineers. The stability of this system is quite remarkable. We have seen a complete change-over from the old d.c. telegraphy to a.c. telegraphy, and the results have thoroughly justified the change. I believe there is a very big field for telegraphs. The telephone should be regarded as a medium for discussion, and the teleprinter should be the means for the communication of definite facts or business communications.

We have arrived at the stage when one can rent a teleprinter instrument and send messages over the telephone circuit. Eventually, however, when we have Mr. Harris's telegraph switching system, we shall have gone a long way towards a co-ordinated telegraph system which will carry messages from one teleprinter subscriber to another, and probably direct from the office of origin to the destination.

To all intents and purposes the problem of line plant for telegraphs has disappeared; the circuits wanted for telegraph purposes can be provided very cheaply indeed by modern methods. Ultimately, when co-axial cables are used over long-distance circuits, it is reasonable to imagine that a certain band width will be leased to the telegraph administration for doing their part of the operation.

The problem which remains is the problem of the delivery of the telegraph message. If someone in Brighton wants to send a telegraph message to someone in Manchester, how is the operator at Brighton to pick out the particular part of Manchester where the message has actually to be delivered? Many proposals have been made, but the problem has not yet been solved satisfactorily. Has the possibility of centring the telegraph system on telephone exchanges instead of on post offices been explored? It may be that 50 years hence one will be able to drop a message into a slot, put 6d. in, push a button, and the message will be delivered at the other end.

Mr. James Frost: I think it will be agreed that the voice-frequency system with its remarkable stability and flexibility has proved very successful in practice, and that the public telegraph service between large towns is better to-day than ever before. During last week-end the majority of the telex installations throughout the country were converted from 300-cycle to 1 500-cycle working. The experience of 300-cycle working has not been very satisfactory, and I should like to know what results we may expect, from the maintenance point of view, with the frequency of 1 500 cycles per sec. In Manchester the official telex circuits are terminated as direct exchange lines on Blackfriars automatic exchange, and very little trouble is experienced with these circuits. This may be due to the fact that the circuits are not very often used, but I am inclined to think that it is because the circuits do not pass through a private branch exchange. In the case of private telex renters the telex set invariably terminates on the renter's P.B.X. and, in the past, a great deal of difficulty experienced on the teleprinter has been attributed to the P.B.X. Without considering the economic aspect of the case, I think that the telex service would be considerably improved if all the installations were terminated as direct lines on a main exchange.

There are one or two points regarding teleprinter instruments, particularly the teleprinter type 7B used on private-wire and telex renters' installations, on which I should like the authors' opinion. I would first mention that there is a privately-owned teleprinter in Manchester fitted with a synchronous motor, and no difficulty is experienced with the installation. It seems to be an uneconomical proposition to provide a rectifier and a d.c. motor when similar results can be obtained by utilizing a synchronous motor connected direct to the public power supply. Some difficulty is experienced with the start-stop device fitted on type 7B teleprinters, and I should like the authors' opinion of the usefulness of this device. With regard to the speed of teleprinter motors, could not matters be so arranged that speed adjustments could be made without it being necessary to remove the protective cover on the governor? It is suggested that a slot might be cut in the cover to allow any adjustments to be made. Experience has shown that when the speed has been adjusted without the cover a slight increase in speed has usually resulted when the cover has been replaced. It is interesting to note that the teleprinter distortion and margin tester and the automatic transmitter have been developed for use in testing teleprinters in the various mechanics' shops, and I hope this apparatus will be available in Manchester in the near future.

In conclusion, I should like to express the hope that full particulars of the through-switching facilities will be made available at an early date.

Mr. H. J. Moores: I notice that 8 minutes is quoted as the average time taken to change an interrupted 4-wire circuit. This delay is mainly caused by having to refer to another branch for the release of the nominated reserve. If this could be picked up immediately, the time would probably be reduced by 75 per cent. The traffic branch could then be notified and would deal with any call which might have been interrupted.

Is the standardization of ± 80 volts only altogether desirable? Considering the many telegraph circuit "locals" in telephone cables, would it not be preferable to make ± 40 volts a standard?

From the limited experience already obtained in Manchester there seems to be little doubt that the general introduction of the static-relay unit will further improve the service and reduce maintenance costs. I should, however, be interested to learn whether, where a station is completely equipped with these units, the complete elimination of send-relay faults has resulted, or whether any fresh type of difficulty has developed. In view of the splendid performance of these units as transmitters, it is a logical step to consider their possibilities in lieu of receive relays. Have any experiments or developments along this line taken place?

The graphs (Figs. 8–12) are very interesting and informative. Were any comparisons made between the channels operating on the higher frequencies and those on the lower frequencies?

Dr. W. Jackson: I do not find the presentation of the technical considerations relating to alternating-current transmission on page 252 nearly so clear as it might have been made. The authors' treatment of distortion under four headings is liable to give the impression that they recognize four distinct mechanisms of distortion, whereas I imagine that they have in mind only three such mechanisms, namely (1) phase distortion, for which I regard "delay distortion" as a more appropriate title since the variation of phase angle with frequency is only significant when interpreted as a variation of transmission time with frequency; (2) amplitude distortion, arising from a variation of attenuation with frequency; and (3) non-linear distortion, concerned with the creation of frequency components which do not exist initially. Each link in the normal transmission system—line, filters, and amplifier—is responsible in either a positive or a negative (compensating) direction for amplitude or phase distortion, and in general for both, and a complete discussion of these two mechanisms would include all the effects which result from restriction of the transmission frequency band. The apparent attachment of independent significance to the latter is therefore liable to be misleading.

Mr. B. J. H. Bitton: The "answer back" system is not yet functioning at Manchester, but traffic officers foresee at least one serious objection to it. It is that the answer back is provided mechanically, irrespective of whether the paper fillet is readable or even moving at all. Given intermittent attention only at the distant office, a failure in this respect would cause much trouble and heavy delay at the zone or area office. With intercommunication added, the failure mentioned would mean a total loss of the telegram transmitted, as the terminal station would have no clue to the source. Perhaps some device may be found which, when paper sticks, will prevent the WRU mechanism from functioning. Foreshadowed developments offer a wide and interesting field for speculation.

Mr. O. Walker: It is of interest to note that the question raised regarding the possibility of difficulty in identifying the correct terminal office for the disposal of telegrams in the larger areas, is already receiving consideration. The proposals provide for the assimilation of the boundaries of the postal-district and telegraph-delivery areas in such a way that each telegraph area will comprise the whole of one or more numbered or unnumbered postal-district areas. Telegrams intended for delivery in these areas would necessarily carry a full postal address for routing purposes.

[The authors' reply to this discussion will be found on page 282.]

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 7TH DECEMBER, 1936

Mr. Alfred Morris: One of the striking points made in the paper is that of the conversion of the telegraphs from d.c. to a.c. operation. The telegraph system of the British Post Office in its present state is most certainly an integral part of the telecommunication system of the country. It takes its place with the telephones; it uses essentially the same line network; it uses at times the mechanical switches at automatic telephone exchanges: it uses the telephone repeater equipment; and, in addition, it shares the engineering staff which maintains the telephone and telegraph system jointly.

The "coaxial cable" is capable of transmitting frequencies of a very much higher magnitude than is possible with the loaded type, and I should like to put to the authors the question as to what are the possibilities of the use for telegraphic purposes of cables of the coaxial type. Further, what are the possibilities of this type of cable for concurrent telegraphic, telephonic, and vision channels? Frequencies of the order of 1 megacycle per sec. can be transmitted over such cables with a reasonable degree of attenuation, but this is not the limit of the frequency range which it is possible to use; frequencies up to at least 5 megacycles per sec. are contemplated. The efficient utilization of such a wide band of frequencies for the simultaneous operation of all the varied types of communications services is probably entirely a question of whether the complex and costly terminal and repeater-station equipment which would be necessary would be justified. In this connection, the length of circuit would obviously be of great importance.

I am interested to see that the authors have dealt with the subject of the sub-audio-frequency channels which are working on particular submarine cables connecting the mainland with some of the islands, e.g. the Channel Islands and the Isle of Man. By making use of the extreme lower end of the frequency spectrum in this way the material medium is utilized to a further extent than the original uses contemplated for it. (These cables were originally intended for telephones or for d.c. telegraphs.) I should like to ask the authors whether it is intended to make use of the sub-audio facilities of any other of the submarine cables, particularly those connecting the mainland of Scotland with the Inner Hebrides or the other northern islands.

Another matter which I should like to put before the authors is the question of the teleprinter motor. I think we have all been impressed by the intricate and thorough testing arrangements which have been devised with the object of checking the speed of the teleprinter motor. I should like to ask the authors whether they have any later information with regard to the use of the synchronous motor.

[The remainder of Mr. Morris's contribution was similar to his remarks at the Manchester discussion (see page 278).]

Prof. E. W. Marchant: The effect that the scheme described in this paper has had in reducing the cost of telegraph messages owing to the reduction in the standing charges on the plant, is of the greatest importance. The growth of the use of the telephone since the reduced rates for trunk calls were introduced is an application of the law which holds very generally between cost and consumption, and there is no doubt that the reduction in cost per message that has been effected by the introduction of voice-frequency signals will lead to a greatly extended use of telegraphy. The developments described in this paper have evidently had a great deal to do with the reduction in the charge for telegrams which has recently been announced. The progress of telegraphy and telephony during the last 30 years has been remarkable. It is due partly to the adoption of loading but mainly to the developments that have been made possible through the invention of the thermionic valve, and the use of repeaters. Engineers can now design lines with zero loss, that is, with no attenuation, without difficulty; this was of course impossible until valves were introduced.

I was interested also in what Mr. Morris said about the use of coaxial cable for high frequencies. The possibility of being able to use frequencies of the order of megacycles opens up a new field of development. We have heard of the possibilities of using high frequencies for telegraphy and telephony, but there is, of course, another application of the coaxial cable that is of interest, namely the use of it for sending television signals from London to the provinces. One of these coaxial cables has already been installed between London and Birmingham, and the Birmingham–Manchester section may be completed in the course of a few months. It seems likely, therefore, that television stations in the provinces may be available within a reasonable time.

Mr. F. Mercer: It is stated on page 239 that the total number of voice-frequency telegraph channels now installed is approximately 1 000, exclusive of some 400 private services. Does this mean 1 000 go and 1 000 return channels? If this supposition is correct the total number of cable pairs required throughout the network appears to be only from 100 to 150, and this must represent an enormous saving in line costs as compared with the old d.c. system, which required not only more cable pairs but also heavier conductors, and even then did not cover as wide an area.

With regard to the simplex point-to-point private teleprinter service, do the routes join up with the 18 channel backbone circuits, or is it essential in such cases for the subscriber to have at his disposal the through use of one or two cable pairs?

Would it not be possible for renters of private lines for telephone service to be given facilities for a supplementary teleprinter service at low cost, using super-audio channels? There must now be available plenty of medium-loaded circuits (88 mH) with sufficiently high cut-off frequency to permit the superposition of a 2-way voice-frequency telegraph channel.

It is stated on page 246 that one of the outstanding advantages of a standard voice-frequency network is that all channels are identical, and can be connected together without previous preparation to provide any desired routing. Surely, however, the ordinary telephone channels cannot be utilized without preparation, as it would appear that in the case of ordinary 4-wire working the echo-suppressors on the telephone channels must be cut out, and further, where voice-frequency telegraphs are superposed on ordinary telephone channels, special echo-suppressors and noise eliminators appear to be necessary.

It is interesting to learn of the probable application of synchronous motors to ensure speed control of teleprinters. In this connection I should like to ask whether the authors have taken into consideration the possibility of frequency variations which may exist between any two separately-operated sections of the grid. I understand that the grid is not always run as a complete network, and variations of frequency are likely to exist on different sections; this might impair the operation of synchronous-motor-operated teleprinters.

Mr. W. K. Edelsten: I should like to ask the authors whether the recent developments in ultra-short-wave radio links are likely to be applied in telegraphy, and also whether the recent researches in 2-wire trunk circuits will affect the telegraph system.

Mr. D. C. Fleming: I should like to ask the authors whether the 18-channel voice-frequency system is now standard or whether the 12-channel, as indicated on many routes in Fig. 2, is preferred when it is sufficient to carry the traffic.

It seems that the 18-channel band is the unit between terminal stations and is presumably amplified at intermediate repeater stations without the individual channels being separated out. Does this give the most flexible arrangement, or would it not facilitate routing if channels could be separated out when required?

The subscriber's apparatus used for the telex system is described as operating at a frequency internationally agreed upon of 1 500 cycles per sec., and presumably when this system is used over a trunk telephone circuit that circuit is occupied exclusively by one telegraph channel operating at this frequency. This seems to be an uneconomical use of the circuit, and I should like to know whether it would be possible to change over to a channel in the voice-frequency telegraph network when a teleprinter message was required to be transmitted.

Reference is made to the use of by-product circuits, such as the phantoms in star-quad cables, for direct-current telegraphy. With the development of voice-frequency working these by-product circuits will no longer be required, and it would be interesting to know whether they will be used for any other purpose.

Mr. W. E. Finlason: I am interested to note that telephone switching principles have now been developed for establishing telegraphic connections, but I feel that we must examine the reasons which have led to their adoption in this field prior to their use for setting up trunk calls.

Am I correct in supposing that the dialling operations involved in setting-up a through trunk call would be far too involved to be entrusted to the care of an ordinary subscriber, whilst the dialling operations involved in establishing a telegraphic channel are slightly simpler and could therefore readily be dealt with by a skilled operator? I imagine that the directory instructions which would have to be placed before the subscriber might be so complicated that he would promptly dial "O" and request his local operator to set the call up for him.

THE AUTHORS' REPLY TO THE LONDON, NEWCASTLE, LEEDS, MANCHESTER, AND LIVERPOOL DISCUSSIONS

Messrs. L. H. Harris, E. H. Jolley, and **F. O. Morrell** (*in reply*): We are grateful to many of the participants in the discussion for the information they have added to the paper, which, however, does not call for reply.

London.

In the development of the switching system for the public service the ultimate possibility of amalgamation with the switched private subscribers' services, which Mr. Thompson mentions, has not been lost sight of. Prior to the building-up of the voice-frequency network, the idea of a separate switched network of physical circuits for private subscribers was cast aside as impracticable and uneconomical compared with the use of telex on the telephone network. The availability of a voice-frequency network makes the separate teleprinter system more attractive, both technically and economically, than was the case under physical line conditions. Nevertheless, it is the possibility of combining the public and private switched services as regards construction, maintenance, and co-operation, that will really make it worth while providing a private teleprinter service apart from the telephone network. Telex is still likely, however, to remain for use when the alternative of speech to teleprinter working is required and when subscribers who have little traffic, and who are distant from a teleprinter switching centre, require connection to the system.

Referring to Mr. Thompson's last point, although channels are lined up on reversals at 33 bauds (2 : 2 at 66 bauds) and test distortion measurements are usually made at 66 bauds, this means that channels can be used indiscriminately for speeds of from 80 bauds downwards. No significance is attached, however, to the low figures that happened to be obtained for 4, 5, and 6 coupled channels in Fig. 10. Adjusting the channels to 50 bauds would give only a negligible advantage on teleprinter circuits, but would seriously affect high-speed channels.

The numbering of the *Avis* of the C.C.I.T. has been modified in accordance with the suggestion made by Mr. Nancarrow. A reference to ancillary working has now been included and an article giving full details added to the Bibliography (Reference 49).

Mr. Aldridge asks for the relative advantages of the two methods of measuring distortion which have been described. It is considered that the cathode-ray tube method is preferable as regards quickness for maintenance measurements of channel distortion. For margin tests of teleprinters and detailed examination of telegraph transmission in which individual signals must be measured, the neon-lamp method with a 7½-unit scale is necessary. Some remarks on the general question of telex working have been made in reply to Mr. Thompson.

It seems likely that in America the long distances concerned have emphasized the importance of economic use of frequency band width as compared with considerations of terminal apparatus costs, and in that country have excluded the use of the ordinary telephone trunks for telegraph subscribers' services. In the British Isles the attractions of a separate telegraph network appear only when such a system is combined, as regards maintenance and provision of plant, with a technically similar system for the public service.

In regard to Mr. Terry's allegation of clumsiness of C.C.I.T. nomenclature, this probably arises through the necessity of being specific. Nicknames no doubt will come later if usage so demands, but too free coinage of words is apt to hinder study, and we see no use in calling an elementary unit anything other than an elementary unit. We have not meant to imply that the C.C.I.T. definition of distortion should be modified to suit the peculiarities of "start-stop." It is better to keep the definition general and of something measurable. The effect of the start signal in the interpretation of measurements must, however, be borne in mind.

The use of regenerative repeaters in the British Isles has not yet been found necessary, nor under the switching scheme is it likely that their use will be necessary except on foreign calls. This is fortunate, since the device, apart from regeneration of teleprinter signals, is complicated by the requirements of dialled impulses, clearing signals, etc.

With regard to half-wave rectification, the particular case given by Mr. Terry was appreciated, but in practice such cases rarely occur owing to necessity for limiting before rectification. As discussed in the paper, the effect of the ideal limiter used in conjunction with narrow band filters is to suppress the whole of the signal envelope except a comparatively narrow strip situated at approximately half the peak amplitude of the signal. These conditions are closely approached in all voice-frequency systems, and, as the modified signal envelope to be rectified is practically "square," the explanation given in the paper applies equally to narrow and wide band transmission.

In reply to Mr. Ritter, if 10 per cent transmission distortion (on account of contact accuracy and speed difference) be allowed, the maximum distortion the receiver on an international link has to face is 38 per cent. This is covered by machines having a margin of ± 35 per cent. This ± 35 per cent may, however, be equal to up to 70 per cent in the same terms as the 38 per cent, and in practice it is believed that the figures laid down by the C.C.I.T. are sound.

As regards the use of a preponderance of receivers only in the switched system, this has already been considered, but questions of standardization, reserve machines, and the necessity, even when receiving, of transmitting the answer-back signal, have led to the decision to use identical machines throughout.

The additions to the Bibliography suggested by Mr. Harrison have been made. His remarks concerning the forked repeater are another instance of the radical changes in transmission methods.

In reply to Mr. Leek, a reference to a recently published article on switching has been added to the Bibliography. The use of voice-frequency instead of physical extensions from switching centres will be adopted when economic, using from 4 to 18 channel systems as required. Where extensions are few and very short, physical lines are cheaper and preferable. A scheme in which the frequencies for transmission from the outstation were generated at the head office was experimented with some time ago in connection with 4-frequency key-sending, but nothing has been attempted as yet in connection with telegraphy.

Newcastle.

In reply to Mr. Smith, it is pointed out that a tariff A circuit is a full-time point-to-point service, and is not therefore a rival to the telex service, which is suitable for short-duration switched calls. With regard to the broadcasting systems, it is only when the system is not in the broadcasting condition, but being used for separate communications to particular outstations, that the number of simultaneous communications is limited by the number of head-office machines.

The variation of distortion with length of 4-wire circuits is somewhat as might be expected in a system in which the various contributing causes are combined in a chance manner to give the overall result.

We agree with Mr. Jordan that the tariff B circuits are two-way simplex so far as their build-up is concerned, but the term duplex is still retained when naming the overall operating condition. The use of the term half-duplex has been discontinued. One hundred words per minute (Wheatstone) is the Post Office guaranteed figure for single voice-frequency channels. Higher speeds naturally must be attainable to enable this guarantee to be given generally. The average system change-over time of 8 minutes is the average from records taken over the whole network.

In reply to Mr. Stanfield, the reduction in faults shown in the graph was due to the measures taken as stated in the paper. Modification of the circuits was carried out as an emergency measure, with immediate success, in order to ameliorate the platinum-iridium contact difficulties, which had become grave in their magnitude. Microscopic needle-like points liable to mechanical locking, which occur with the former, do not occur with copper-palladium contacts, although ordinary points and craters still occur and the mass of metal worn may be greater than with platinum.

Marking bias appears at high speeds on voice-frequency channels because, with short signals, due to the build-up time of the filters there tends to be neither complete suppression of the tone nor complete return to full amplitude. The sensitivity of the amplifier-rectifier increases owing to the reduction in the peak amplitude of the voice-frequency signals, and marking bias results.

Mr. Stanfield need not be apprehensive that the voice-frequency system will be called on to exceed its extensive capabilities. Naturally the more links in tandem the lower the maximum speed, and stability is sacrificed if any circuit is pushed to the utmost limit of speed.

In reply to Mr. Anderson, the attenuation of the filters on multi-channel voice-frequency equipment is checked in the pass band at the mid-band frequency, and in the attenuating ranges at frequencies 120 cycles per sec. higher and 120 cycles per sec. lower. The test currents, obtained from the multi-frequency generator, are applied in turn to a special test detector used as a valve voltmeter, alternately through the filter and an attenuator, the attenuator being adjusted in each case to give the same reading on the valve voltmeter.

Leeds.

It might be concluded from Mr. Tyson's remarks on distortion that printing-telegraph systems will only operate over circuits having little or no distortion. This, however, is far from the case. The teleprinter will permit variations of 35 per cent and over in the time intervals of the signals, while some synchronous systems will permit variations of 70 per cent or more.

Mr. Tyson also says that there must be some limit beyond which it ceases to be economic to complicate the working equipment. This is agreed, but it seems certain that even with full automatic switched telegraphy this limit will not be exceeded. An article relating to switching has recently been published, and a reference has been added to the Bibliography.

Mr. Murray mentions the tendency towards a diversion of traffic from normal telegraph service to private teleprinter services. The modern business tendency is, however, to forward by teleprinter matter which in the past has been sent by post, and so speed up sales services, etc., by 24 hours.

Mr. Adams suggests series instead of short-circuiting contacts for the modulation of the tone in voice-frequency telegraph systems. This question was examined in detail some years ago and the short-circuiting method found preferable owing to the effect of transit time on the self-regulating bias at the receiving end, and therefore on the telegraph distortion.

Mr. Adams also raises the old question of whether "carrier" is the correct term for interrupted tone signals. It can be shown that interrupted tone is equivalent to continuous tone modulated with the signal frequency and all its harmonics, and therefore it is suggested that the general heading of "carrier" is appropriate.

Mr. Robinson asks for the meaning of the footnote on page 241. It is possible, of course, to devise teleprinting systems in which each letter corresponds to the combination of frequencies transmitted, as in 4-frequency key-sending in telephony. Here the time per letter could be much smaller than with time codes, but the frequency band required would be correspondingly greater. For keyboard operation the additional speed could not be made use of, since the operator's typing speed would be much lower. Were it not for consideration of standardization, there might be some advantage of such a type of machine for obtaining a "freer" keyboard on telex circuits where the full telephone frequency band is available.

The production of odd harmonics occurs in repeater and line transformers and loading coils, and the absence of trouble is due partly to the low power level and also to the relatively small frequency range (approximately 360 to 2 520 cycles). Some trouble is experienced, however, on super-audio channels at frequencies close to the cut-off frequency of the cable circuit. With the level of 10 μW per channel at a point of zero level in a 4-wire circuit, the possible peak power at the repeater output is 32·4 mW, which approaches the maximum power-handling capacity of the repeater output valve.

Mr. Hall's reference to the possible effect of a click on telex transmission is perhaps misleading. The effect to which he refers is that whereby in certain circumstances a momentary click, if occurring in an interval between two characters of more than 130 milliseconds, can cause the receiving teleprinter, if operating in the upper case, to revert to the lower case, so printing letters instead of figures. Measures have been taken to avoid such clicks on telex connections, and the possibility of this occurring is now extremely remote, probably less than once per 50 000 characters transmitted.

With regard to direct-current tariff A services, these will still continue to be used where by-product circuits are available. The use of voice-frequency channels is resorted to where by-product circuits are not available.

Manchester.

Mr. Morris mentions that the spacing of 120 cycles per sec. is suitable for speeds of 50 to 60 words per minute. In case this should be misunderstood, it is well to point out that these speeds allow a very big margin indeed on single-channel circuits and so enable tandem channels to be used.

Mr. Morris criticizes the phrase "inefficient use of band width," but it seems appropriate enough to describe the case where a width of band is used for a purpose which could be accomplished by a much smaller one, d.c. telegraphy for example.

The work of the C.C.I.T. has, as Mr. Morris says, been of great value in clearing the way for standardization of telegraph methods and apparatus. For example, providing all countries develop their national teleprinter services according to the agreements which have already been reached as regards speeds, keyboards, codes, and frequencies, nothing vital technically remains to prevent the complete international co-operation of all types of teleprinter services.

In reply to Mr. Herbert, it is believed that voice-frequency methods are used to a large extent in the United States for providing channels for their teleprinter exchange service. Mr. Walker has kindly given the answer to Mr. Herbert's query regarding the difficulty of knowing from the address the correct delivery office to which a telegram must be transmitted.

The change from 300 to 1 500 cycles per sec. for telex working, mentioned by Mr. Frost, was made to conform to the internationally agreed frequency, which was chosen as it has several advantages over other possible choices. Some difficulties have been experienced on telex service on private branch exchanges and, although measures have been taken to overcome them, wherever possible the telex line is taken direct to the telex position. A switch is provided to give alternative facilities via the private branch exchange, if and when required. The design of the automatic motor switch on the teleprinter has recently been reviewed and changes have been made which should remove the present difficulties.

We agree as regards the method of changing faulty 4-wire circuits mentioned by Mr. Moores, but so far authority has not been obtainable for seizing, without warning, a telephone circuit which may be in use by two trunk telephone subscribers. As it is demonstrable that this would have only a negligible effect on the telephone service, the matter may ultimately receive favourable reconsideration.

As 80 volts is preferable to 40 volts for operating the receiving electromagnet of teleprinters, and as it is desirable to standardize on one voltage, the former figure has been decided upon.

The only point that must be borne in mind in using static relays as compared with ordinary transmitting relays is that when considering switched channels it is more important with static relays that at no time during the preliminary calling or subsequent clearing procedure should the controlling direct current be interrupted (as distinct from the normal reversal).

The question of replacement of receiving relays, mentioned by Mr. Moores, has already been covered in the paper.

There is some evidence that the distortion on the 420-cycle channel is slightly greater than on the higher channels, but this is so small as to be of no practical importance.

It is agreed that the line characteristics can be considered under the three mechanisms suggested by Dr. Jackson, and in the mathematical treatment of the subject such would be the case. We wished, however, to present a mental picture of the effects resulting from certain well-defined characteristics which occur in practice, and for this reason the four characteristics were mentioned separately. As phase distortion arises primarily from the non-linearity of the phase characteristic, it is considered that "phase distortion" is the more appropriate term.

The importance of paper failure, mentioned by Mr. Bitton, has not been lost sight of in consideration of the switched telegraph system, and recently several promising schemes for checking both the presence and correct movement of the tape have been devised and examined. It is likely that use will be made of the answer-back unit to give warning at the sending end of paper failure at the receiving end.

Liverpool.

In reply to Mr. Morris it appears that each telephone channel obtained on a "coaxial cable" should be capable of being used for multi-channel telegraphs. It will be appreciated, however, that the degree of accuracy of carrier frequency becomes of greater importance on high-frequency carrier telephone channels.

Cases of possible simultaneous telephone and telegraph facilities such as those mentioned by Mr. Morris have received consideration, but in no instances other than those mentioned in the paper has the sub-audio method been considered the most desirable of the several possibilities available.

As regards the use of synchronous motors for driving teleprinters, the field trials which are still in progress indicate that a satisfactory solution of the problem is within measurable distance.

In reply to Mr. Mercer, there are 1 000 duplex channels making use of 70 four-wire telephone circuits. Simplex point-to-point private teleprinter services are provided on voice-frequency channels or by-product circuits. Reference is made in the paper (page 252) to experiments at present in progress on an 8-channel super-audio system. The statement on page 246 refers to the channels themselves. It is true that the echo-suppressors must be cut out when a 4-wire circuit is used for voice-frequency telegraphs, but this is only a minor change. The possibility of frequency variations affecting the speed of synchronous driving-motors has been borne in mind, but there is no evidence to show that the speed differences to be expected are important in magnitude.

In reply to Mr. Edelsten, experiments have already been made, and further tests are envisaged, on ultra-short-wave radio links.

In reply to Mr. Fleming, the system is standard whether 12 or 18 channels are used. Space is left, when 12-channel systems are installed, for future development to 18 channels.

It is true that, in the case mentioned, a telex call occupies a telephone channel exclusively, but the facility of speech as an alternative may be required; also the overall economy of this system of working is dependent on other considerations in addition to that of frequency band. There appears to be no reason why by-product circuits should not continue to be used for telegraph services.

It is no doubt true, as Mr. Finlason remarks, that the dialling operations involved in setting up a through telephone trunk call are likely to be more involved than in the telegraph case, but this is only one of a number of important respects in which the two cases differ.

ULTRA-SHORT-WAVE REFRACTION AND DIFFRACTION*

By T. L. ECKERSLEY, B.A., B.Sc.

(*Paper first received* 10*th December*, 1935, *and in final form* 20*th October*, 1936.)

SUMMARY

The work of G. N. Watson on the propagation of electric waves over a spherical earth has been extended by the author to take account of the finite resistivity of the earth, the effect of which is of great importance in ultra-short-wave transmission.

The work is in such a form that the field intensities above the earth can be computed numerically. The effect of refraction in the earth's atmosphere can also be taken into account. The results for a range of wavelength between 2 and 10 m and for heights up to 4 000 m and distances up to 400 km, are published in the paper in a set of curves, the general properties of which are discussed.

The effect of atmospheric refraction is considered, and a comparison between observation and theory is made, in which good agreement is obtained, on the average, when neglecting refraction. Major changes may, however, be produced occasionally by refraction.

PROPAGATION CURVES FOR ULTRA-SHORT WAVES

It is probable that in the near future ultra-short waves, i.e. those below 10 m, will be extensively exploited for television and for short-distance point-to-point and aircraft communications. It is therefore essential to know the ranges and physical transmission properties of these waves. The curves reproduced in this paper are intended to give this information in graphical form.

The curves show the field intensity for all distances up to 400 km and at all heights up to 4 000 metres, produced by a vertical doublet—a radiator so short as to give a cosine diagram—situated on the earth's surface and radiating 1 kW. Also, by the reciprocal theorem, the roles of receiver and sender can be reversed, so that the curves give the field produced by a raised transmitter at a receiver on the surface of the earth, within the ranges of height and distance already specified. Finally, they can be made to give the field at any given height h_1, from a transmitter at any other height h_2, measured above the spherical earth surface.

As in the case of the longer-wave broadcast transmission, the field depends to a great extent on the earth's conductivity (σ) and permittivity (κ), but whereas, in the long-wave case, oversea transmission can be regarded as equivalent to transmission over a perfect conductor, at the ultra-short wavelengths the behaviour over sea departs very markedly from that for transmission over a perfect conductor. Curves are therefore calculated for the following earth constants (in e.m.u.): $\sigma = 10^{-13}$, $\kappa = 5$, for overland transmission; $\sigma = 10^{-11}$, $\kappa = 80$, for oversea transmission. Although the curves are self-sufficient, a few words of explanation are required to indicate the assumptions made and the limitations involved.

Ultra-short-wave transmission has generally been treated by the methods of geometrical optics. Thus, in Fig. 1, a transmitter T at a height h_1 is supposed to have a visual range TR, where R is so chosen that the plane TR is tangential to the earth's surface at R.

The points on the surface of the earth beyond R are in the shadow of the "bulge" of the earth, and, according to geometrical optics, nothing would be received at such distances.

As a concession to the wave theory, it is generally admitted that some energy leaks into the shadow region, but the amount of spread is generally left to guesswork. Some such concession is necessary, because otherwise, according to the geometrical ray theory, a transmitter on the surface of the earth should have practically no range at all. It is clear that the problem is not one of geometrical optics but one that requires the full wave theory for its solution.

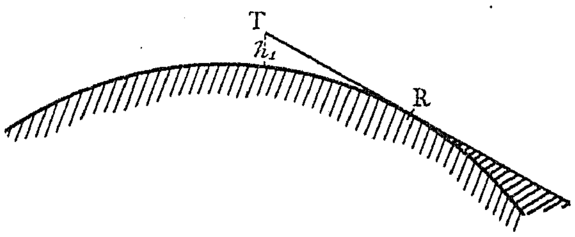

Fig. 1

This theory has been worked out by many eminent mathematicians, including Poincaré, Nicholson, Love, and MacDonald. A certain amount of disagreement was cleared up by the work of G. N. Watson, and it is generally admitted that his mathematical results are beyond reproach.

The following well-known diffraction formula, giving numerical results, has been derived by Van der Pol from Watson's analytical results:—

$$\epsilon = \frac{0 \cdot 5386 hIe^{-23 \cdot 9\theta/\lambda}}{\lambda^{\frac{7}{6}} \sin^{\frac{1}{2}}\theta}$$

where ϵ = field intensity, in millivolts per metre; h = "effective height," in km; I = current (r.m.s.), in amps.; λ = wavelength, in km; and θ = angular distance between transmitter and receiver. In the derivation of this formula it was assumed that, in effect, the conductivity of the earth was so high that it could be considered a perfect conductor; again, the field at a height above the earth's surface was not considered. Thus the formula is not adequate to describe the behaviour of ultra-short-wave transmission where the

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

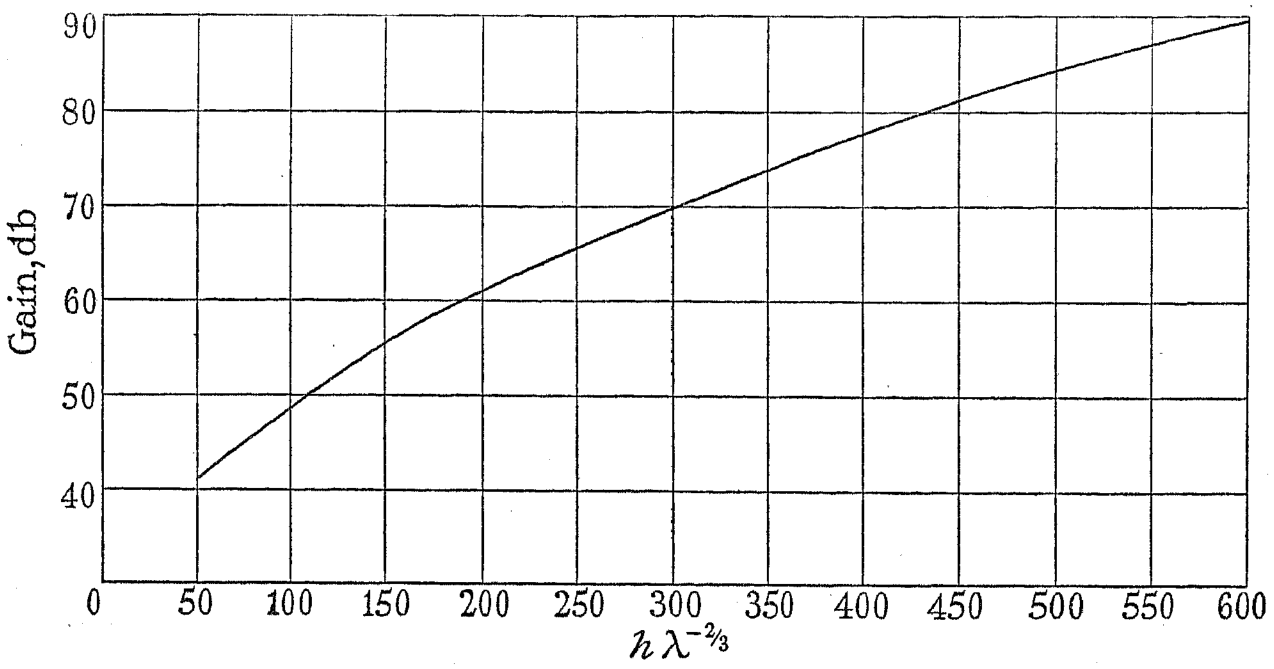

Fig. 2.—Height/gain curves (h and λ in metres).

The following are the figures of decibels to be subtracted:—
Land. 2 m, 0 db; 4 m, 2·2 db; 6 m, 3·7 db; 8 m, 4·9 db; 10 m, 5·9 db.
Sea. 2 m, 13·6 db; 4 m, 18·0 db; 6 m, 20·8 db; 8 m, 22·9 db; 10 m, 24·4 db.

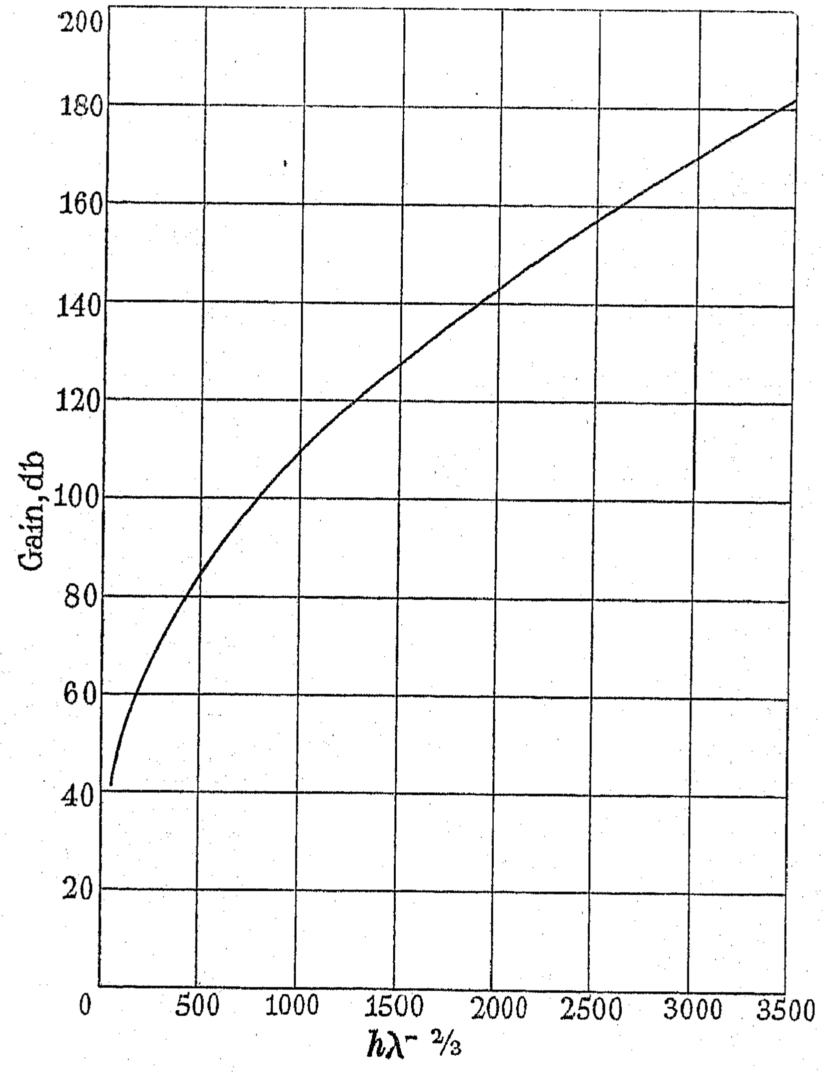

Fig. 3.—Height/gain curves (h and λ in metres).

The following are the figures of decibels to be subtracted:—
Land. 2 m, 0 db; 4 m, 2·2 db; 6 m, 3·7 db; 8 m, 4·9 db; 10 m, 5·9 db.
Sea. 2 m, 13·6 db; 4 m, 18·0 db; 6 m, 20·8 db; 8 m, 22·9 db; 10 m, 24·4 db.

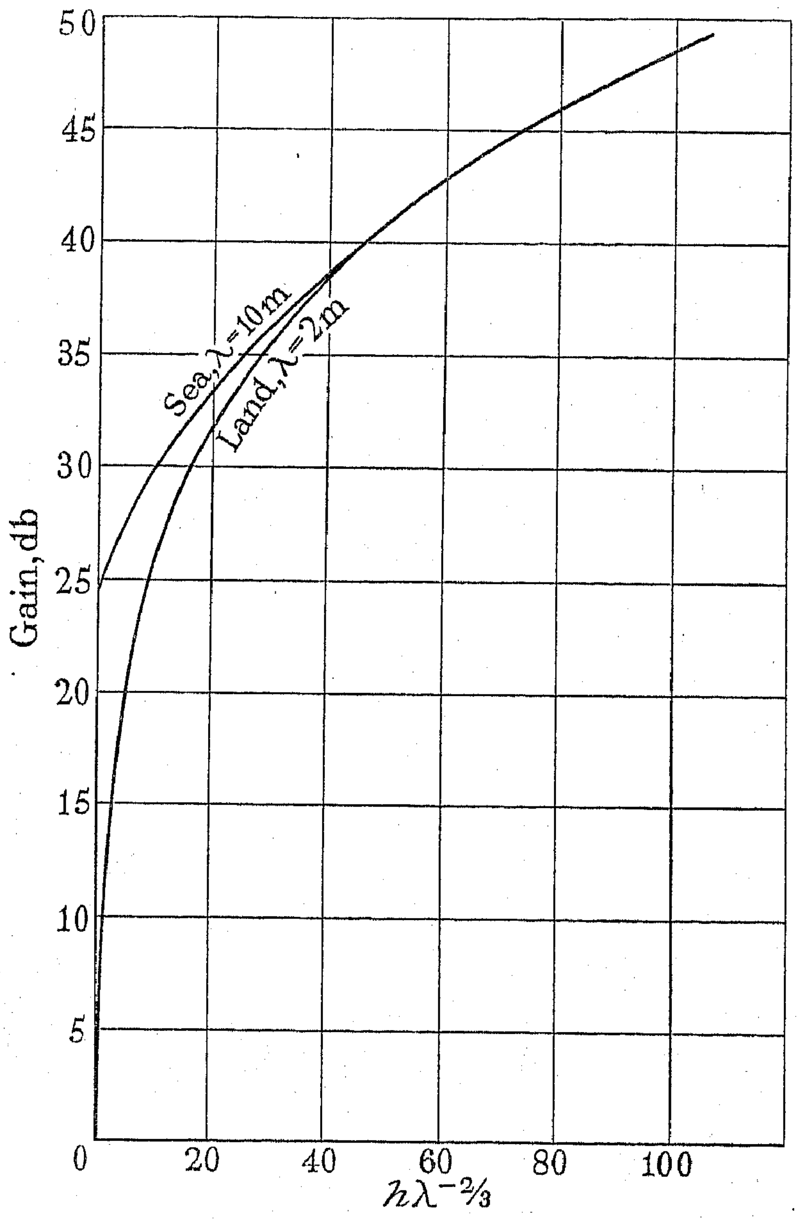

Fig. 4.—Height/gain curves (h and λ in metres).

The following are the figures of decibels to be subtracted:—
Land. 2 m, 0 db; 4 m, 2·2 db; 6 m, 3·7 db; 8 m, 4·9 db; 10 m, 5·9 db.
Sea. 2 m, 13·6 db; 4 m, 18·0 db; 6 m, 20·8 db; 8 m, 22·9 db; 10 m, 24·4 db.

effect of the height of the receiving and transmitting aerial requires to be known and where the effect of the earth's constants must be included. A short-cut method enabled the present author* to determine the modification of the exponential factor in the above equation due to the finite conductivity of the earth. A development of this method, by which certain characteristic numbers involved in Watson's solutions can be recalculated for the case of finite earth conductivity, has enabled the complete solution to be obtained at various heights and distances. The results are in such a form that the effect of atmospheric refraction can be included. The curves here presented are derived from these mathematical results, but the effect of refraction is neglected. They are based, therefore, on the assumption that the earth is of uniform conductivity σ and permittivity κ, and that the permittivity of the regions outside the earth is constant and equal to unity. The general solution is obtained as the sum of a number of terms of which the first is predominant at sufficiently large distances and for sufficiently small heights. The curves (Figs. 6–25) are calculated in the regions where the first term is predominant. In each figure, the broken line gives the inverse distance field for propagation over a plane perfectly-conducting earth. The estimated uncertainty in the curves outside these regions is not greater than 2 or 3 db.

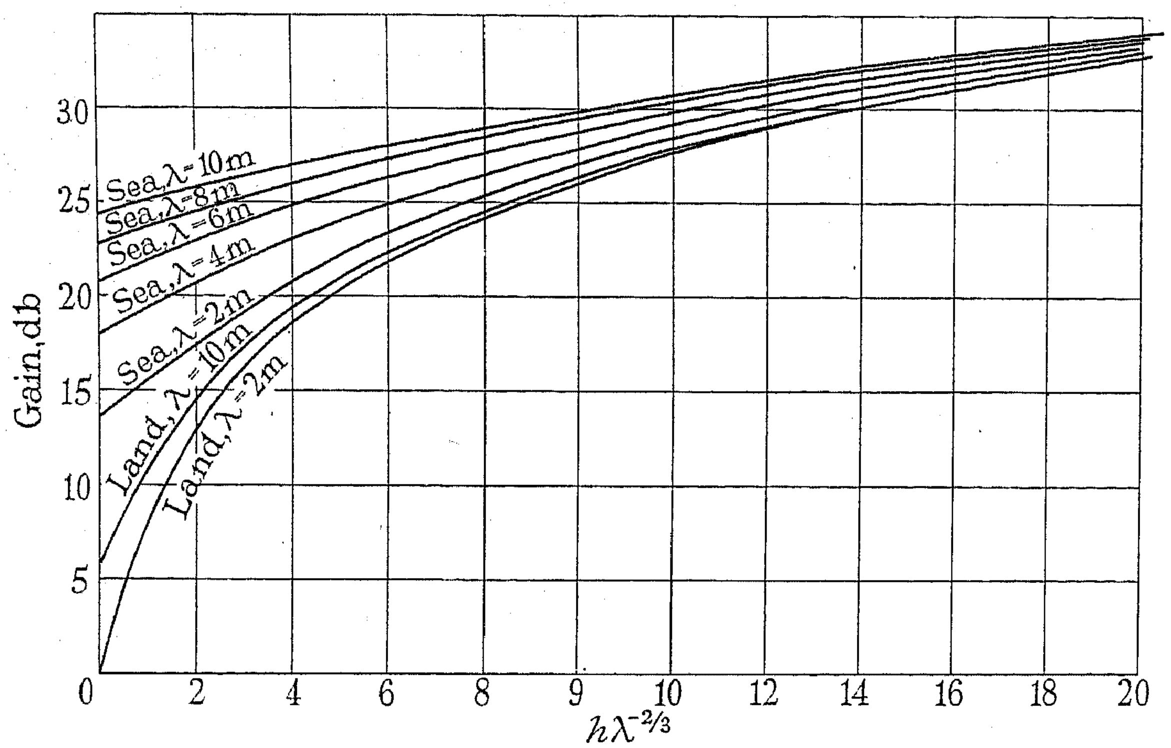

Fig. 5.—Height/gain curves (h and λ in metres).

The following are the figures of decibels to be subtracted:—
Land. 2 m, 0 db; 4 m, 2·2 db; 6 m, 3·7 db; 8 m, 4·9 db; 10 m, 5·9 db.
Sea. 2 m, 13·6 db; 4 m, 18·0 db; 6 m, 20·8 db; 8 m, 22·9 db; 10 m, 24·4 db.

CHARACTERISTICS OF CURVES

The most obvious feature of the curves is that in the region where the first term of the diffraction formula is predominant, the curves for various heights are all parallel. This implies that the gain in decibels resulting from an increase in height of receiver (or transmitter) above the earth's surface, is independent of the distance from the transmitter. Again, on ultra-short wavelengths the slope of the curves (loss, in db per km) is independent of the earth constants.

Finally, a close scrutiny shows another general property possessed by the curves, a property which is also, of course, implicit in the mathematical analysis. It is this: above a certain height h_0, which is only a slowly varying function of the wavelength, the gain in field strength with height is, to a high degree of approximation, independent of the earth constants. It is consequently only a function of h and λ in the form $f(h\lambda^{-\frac{2}{3}})$. Experimental measurement of the height/gain relation, as well as measurements of the slope of the field-intensity/distance curves, afford, therefore, a very useful check on the theory, since in this comparison between observation and theory no doubtful earth-constants are involved. A single master curve, in which the gain in decibels above h_0 is plotted as a function of $h\lambda^{-\frac{2}{3}}$, can therefore be constructed. This auxiliary curve is shown in Figs. 2 and 3. It gives the part of the curve for the height/gain relation for heights above h_0. The value of h_0 is such that $h_0\lambda^{-\frac{2}{3}}$ is practically equal to 50.

An example will make the use of this curve clearer. Thus, if we wish to know the ratio of the field intensity at a height h to that at h_0, we first calculate $h\lambda^{-\frac{2}{3}}$ (h and λ are expressed in metres). Suppose h is 800 m and λ is 8 m; then $h\lambda^{-\frac{2}{3}} = 200$. The value on the decibel scale corresponding to this is 61 db. The value at h_0 is 41 db. Therefore the ratio of the signal intensity at $h = 800$ m, $\lambda = 8$ m, to that at h_0 is (61 − 41) db, i.e. 20 db, or 10 to 1.

Below h_0, however, the height/gain relation is very sensitive to the earth constants. Thus, in raising the receiver or transmitter from the ground to a height h_0, there is a very much greater gain over land than over sea. This is shown in Figs. 4 and 5, where the single curve giving the relation between $h\lambda^{-\frac{2}{3}}$ and decibels gain, which is appropriate for $h\lambda^{-\frac{2}{3}} > 50$, fans out into a sheaf of curves for different values of the earth constants and wavelengths in the region where $h\lambda^{-\frac{2}{3}}$ lies between 0 and 50. Figs. 2–5 can be used to obtain the gain intensity above the ground intensity by using the figures appended to the curves. Thus, if we obtain directly from the curves the decibels corresponding to a given height h, then we have only to subtract the figure appropriate to the nature of the transmission (e.g. for

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* *Proceedings of the Royal Society*, A, 1932, vol. 136, p. 499.

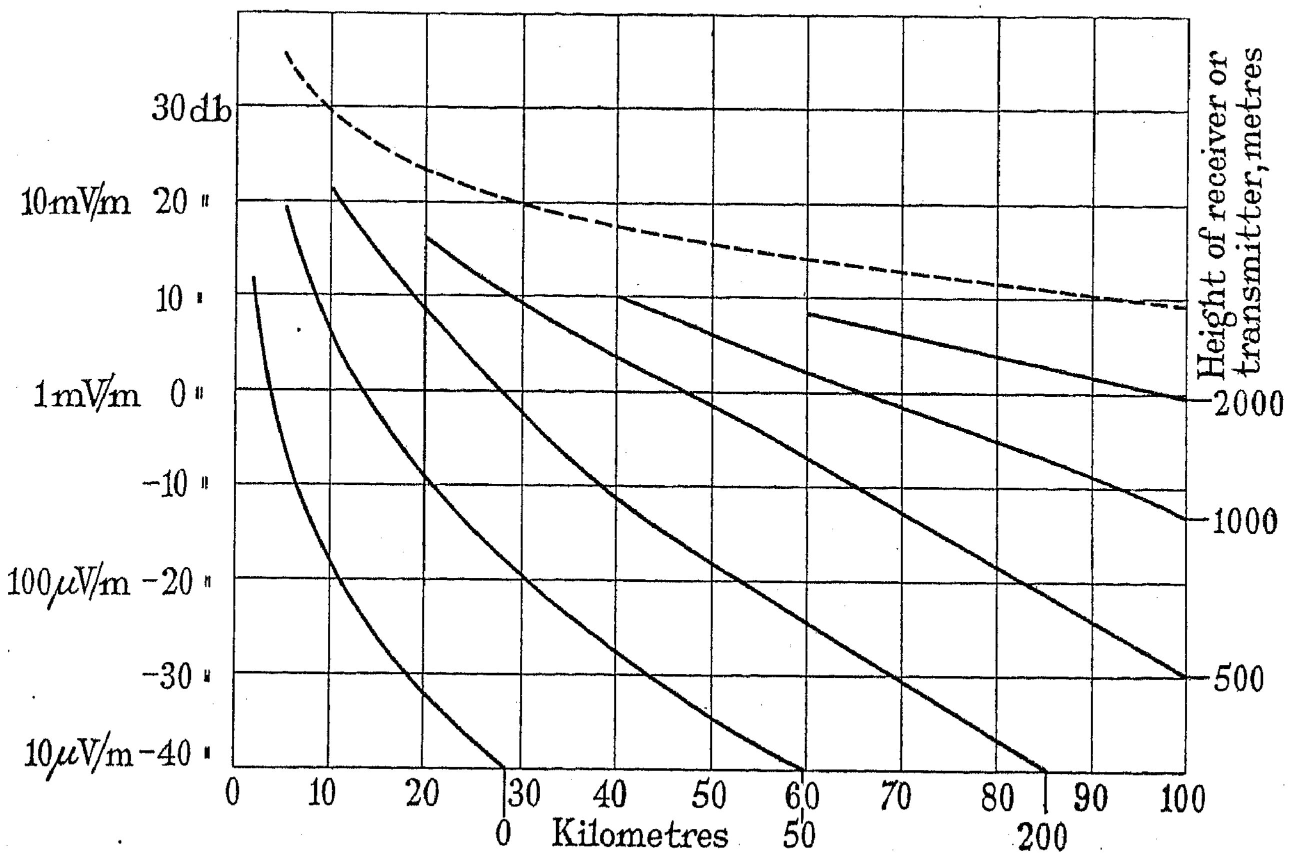

Fig. 6.—Results obtained over sea; $\lambda = 2$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

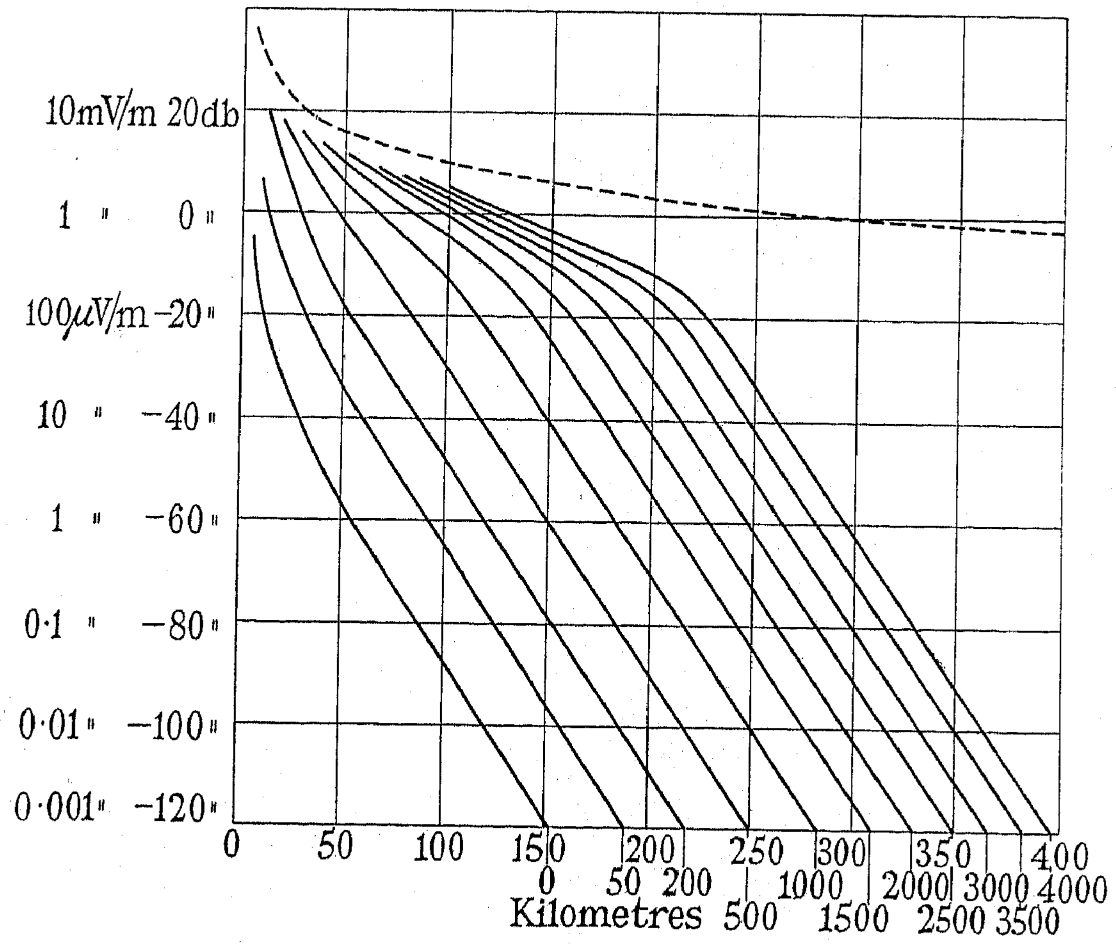

Fig. 7.—Results obtained over sea; $\lambda = 2$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.
Figures against curves indicate height of receiver or transmitter in metres.

8 m over land, 4·9 db) to obtain the gain (on a wavelength of 8 m) due to raising the receiver to a height h above the land.

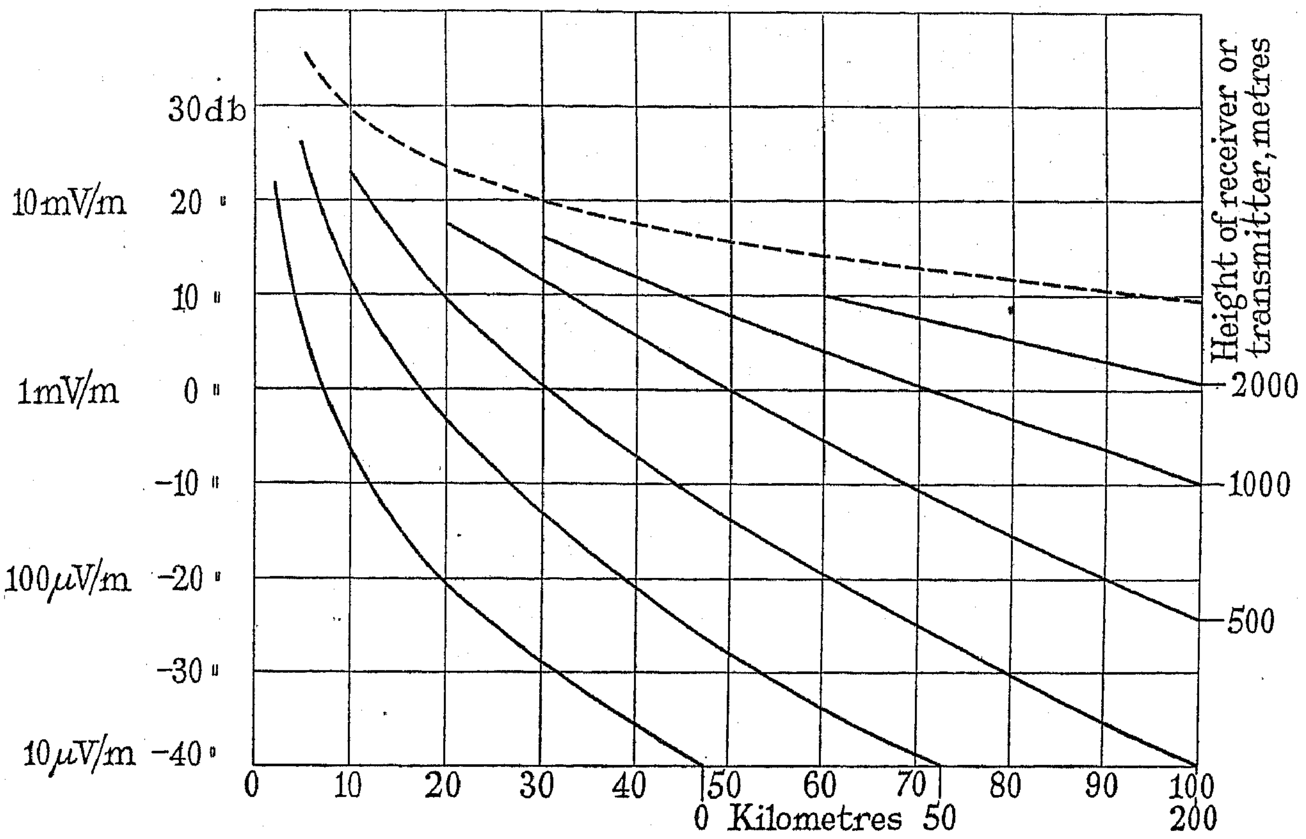

Fig. 8.—Results obtained over sea; $\lambda = 4$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

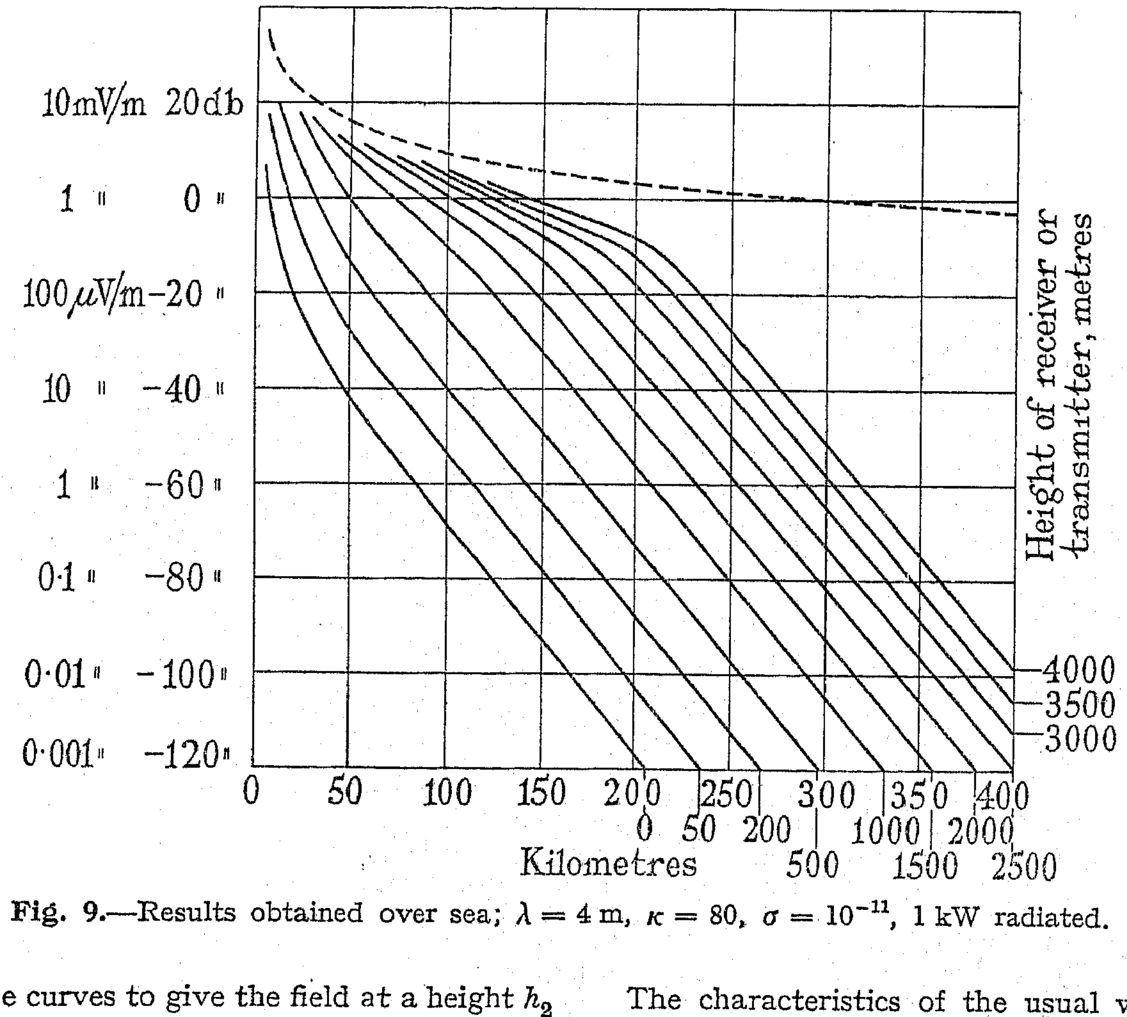

Fig. 9.—Results obtained over sea; $\lambda = 4$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

We can use these curves to give the field at a height h_2 at the receiver due to a transmitter at height h_1. Thus the field on the ground at the required distance from a transmitter at height h_1 is first determined from the curves (Figs. 6 to 25), and then the gain on raising the receiver to a height h_2 is given by the curves of Figs. 2, 3, 4, and 5. The resultant field is thus found.

The characteristics of the usual working theory, in which diffraction effects are only introduced beyond the geometric " visual " range, are illustrated diagrammatically in Fig. 26. The field (curve A) maintains its inverse distance characteristics up to the visual range, after which it drops suddenly in the shadow region. The true curve for heights above 200 metres illustrates these characteristics, though the point of inflection P at the visual range is very much rounded off, and the actual field at the visual range is some 10 to 30 db below the unobstructed (inverse distance) value. Thus at sufficient height and distance, transmission behaves approximately as the rough working theory suggests. On the other hand, for the lower heights, up to 200 metres or so (curve B), such as might be used in television practice, there is absolutely no indication on the curve of any inflection such as occurs at the visual range in the other cases.

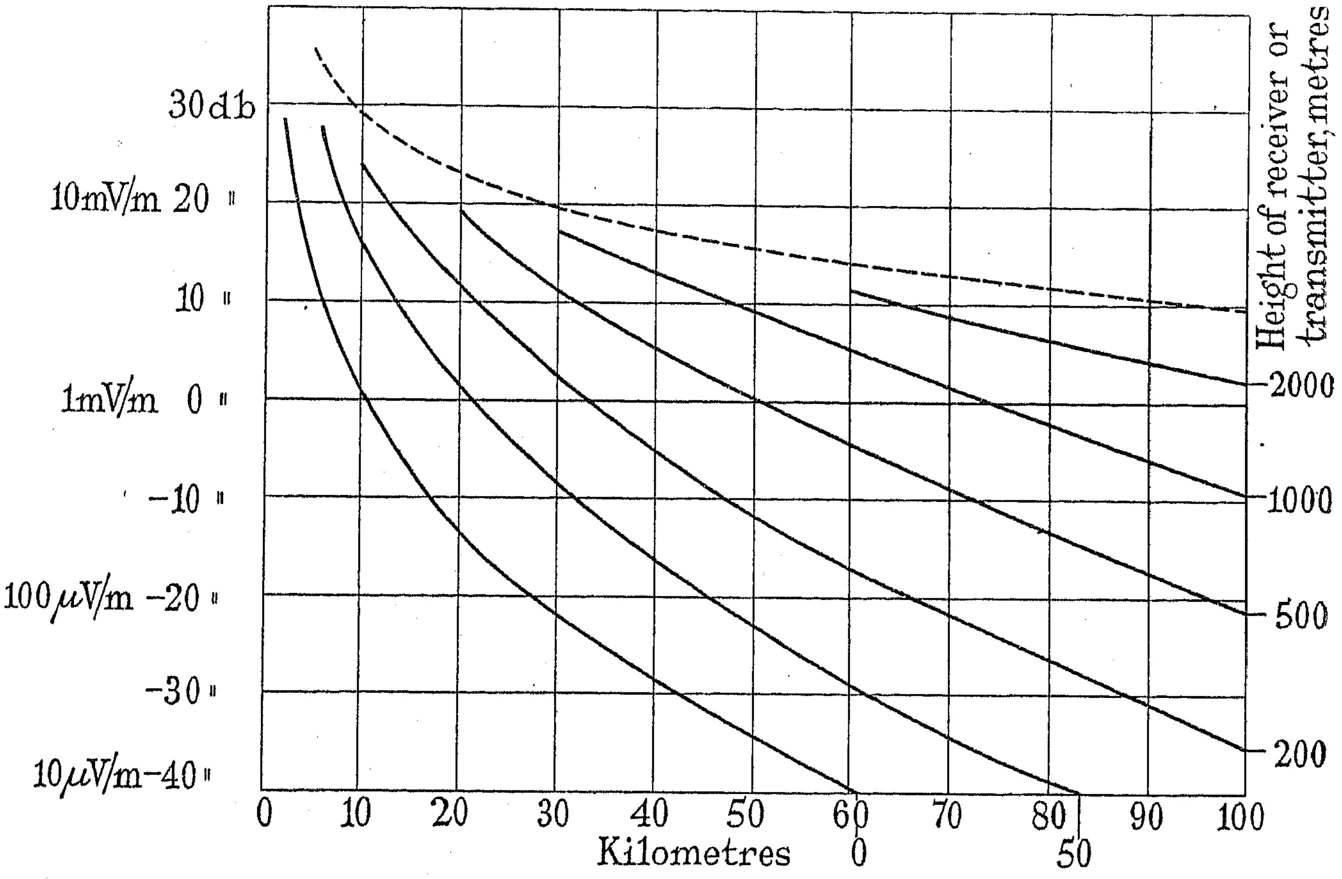

Fig. 10.—Results obtained over sea; $\lambda = 6$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

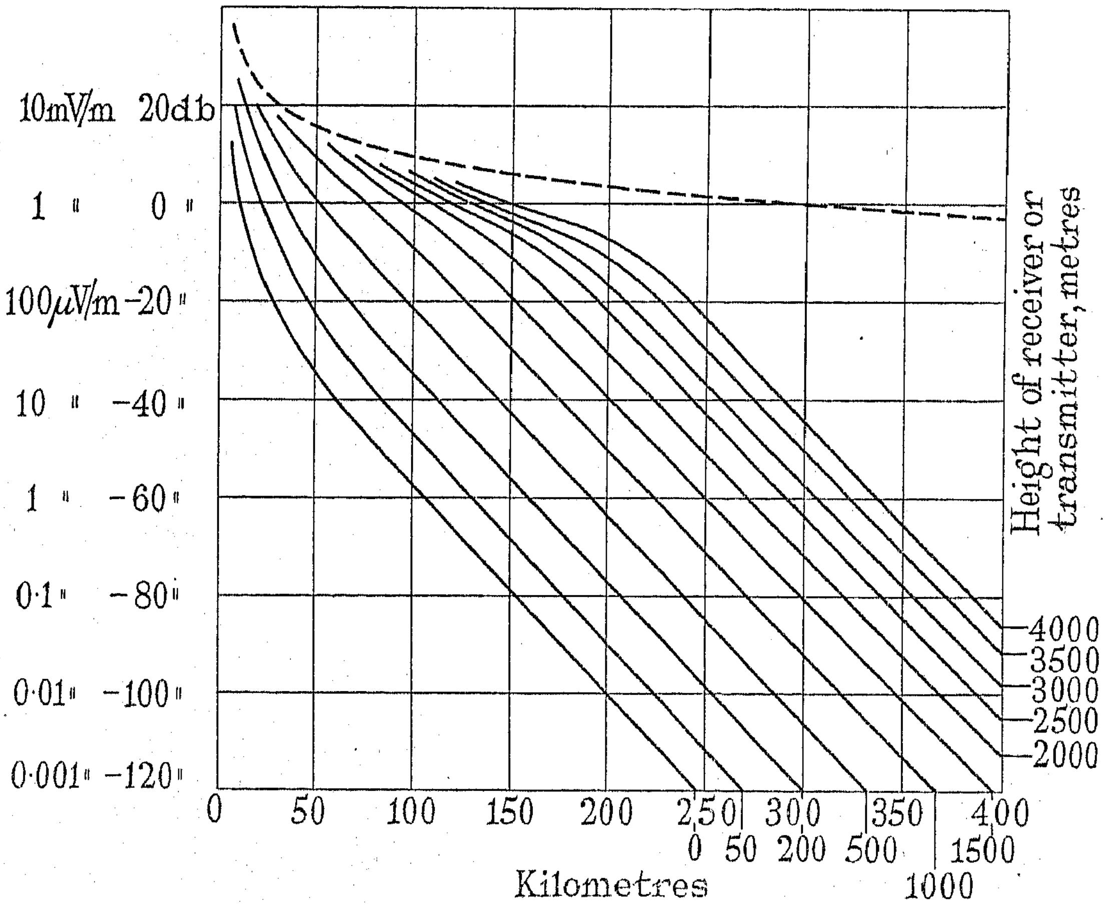

Fig. 11.—Results obtained over sea; $\lambda = 6$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

To express the results in terms of visual range, in the expectation of a sudden drop of field strength beyond this, is, if not false, at least meaningless. Physically, the meaning of the results is fairly clear. The earth has taken such a toll of energy in the case of relatively low transmitters, even within visual range, that the extra shadow effect beyond this range is entirely obscured.

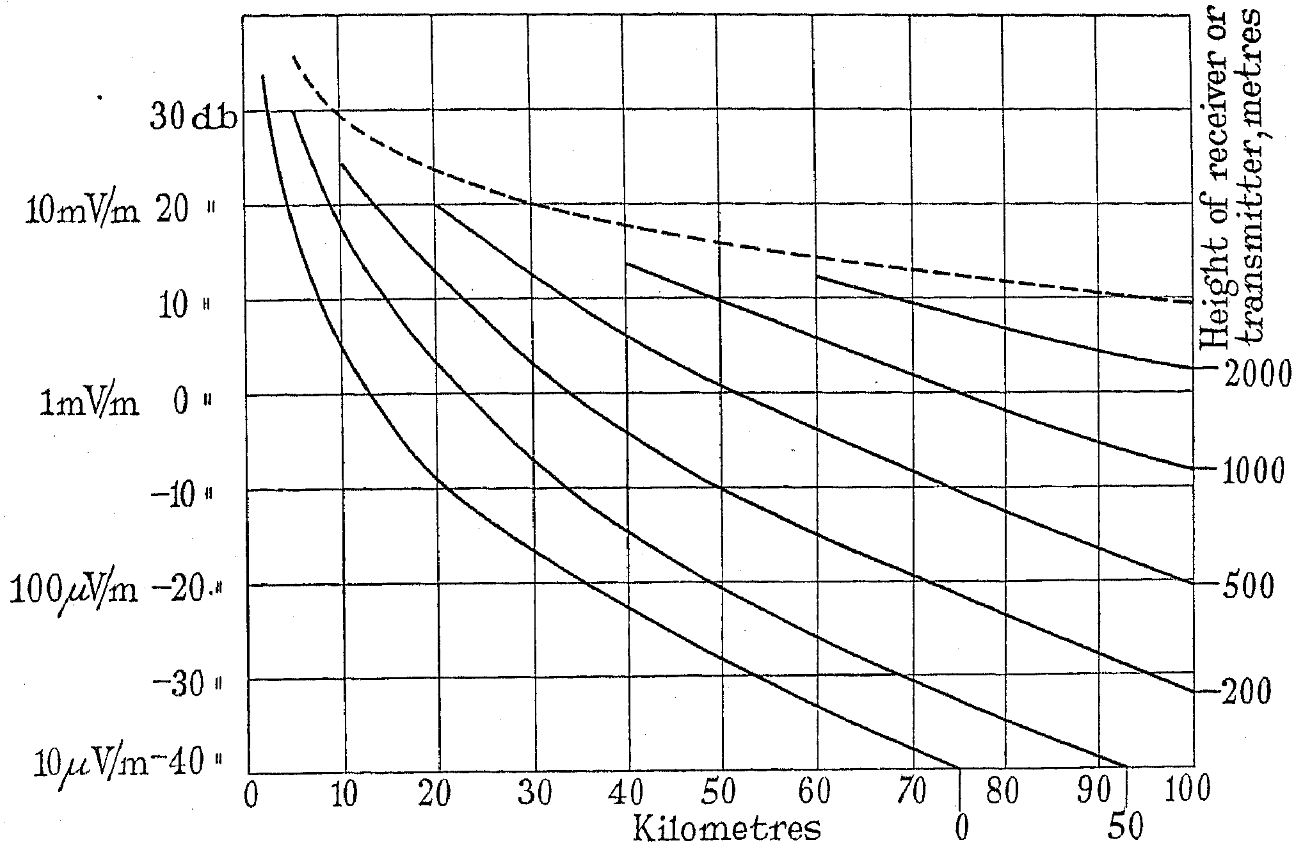

Fig. 12.—Results obtained over sea; $\lambda = 8$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

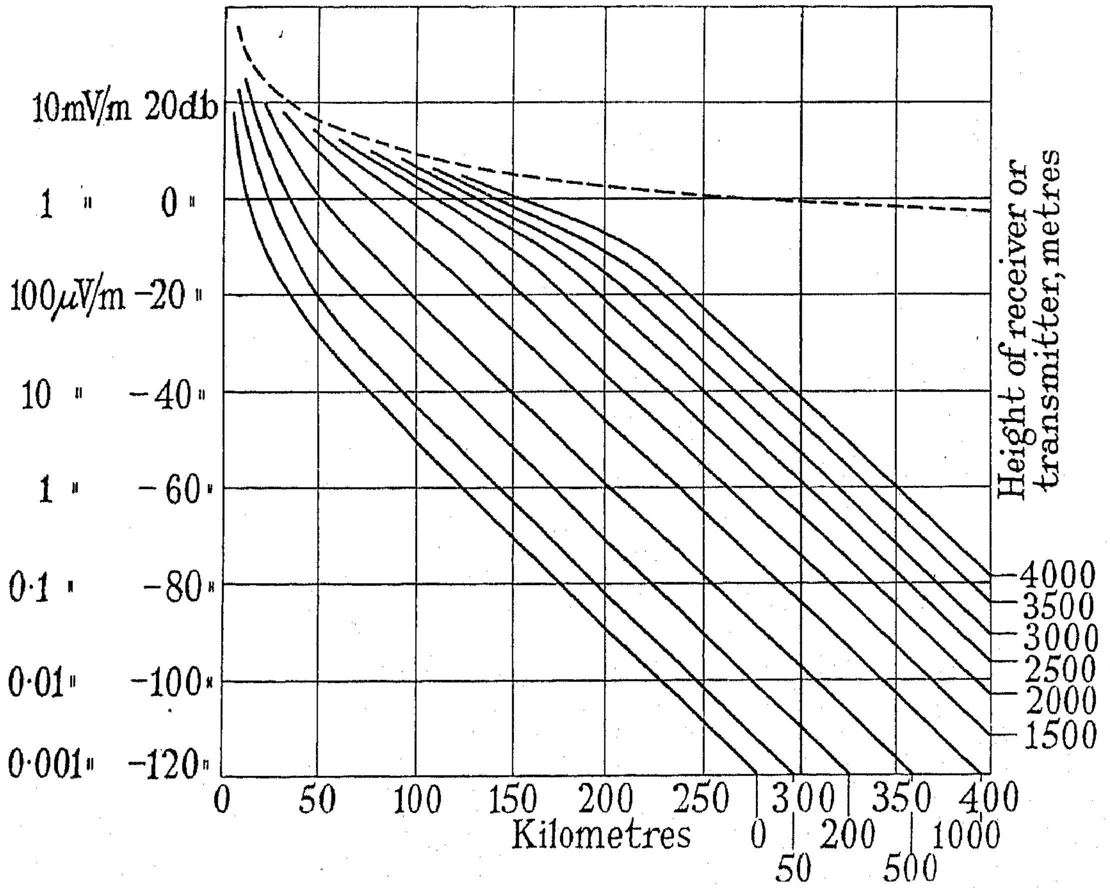

Fig. 13.—Results obtained over sea; $\lambda = 8$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

This characteristic, namely the absence of marked quasi-optical visual-range effect, is associated with the following fact noted in the mathematical treatment. It is found that the results can be expressed in a quasi-optical manner with respect to a fictitious radius (R_0) of the earth which is greater than the actual radius (R). The difference between R_0 and R is of the order of

200 metres, for a wavelength of 10 metres, and is a slowly varying function of the wavelength as well as of the earth's constants. The height, $R_0 - R$, is the height h_0 referred to in the previous paragraphs, and is shown in Fig. 27 as a function of the wavelength. It is only when the transmitter (or receiver) is well above this radius that the quasi-optical visual-range effects begin to appear. These results are illustrated in Fig. 28(*a*), from which it is obvious that, if the height of the transmitter is less than $(R_0 - R)$, no meaning can be attributed to visual range in the altered sense described above. This leads to the following practical rule: If unobstructed transmission is required between points T and B, the line TB must not approach the earth nearer than $(R_0 - R)$.

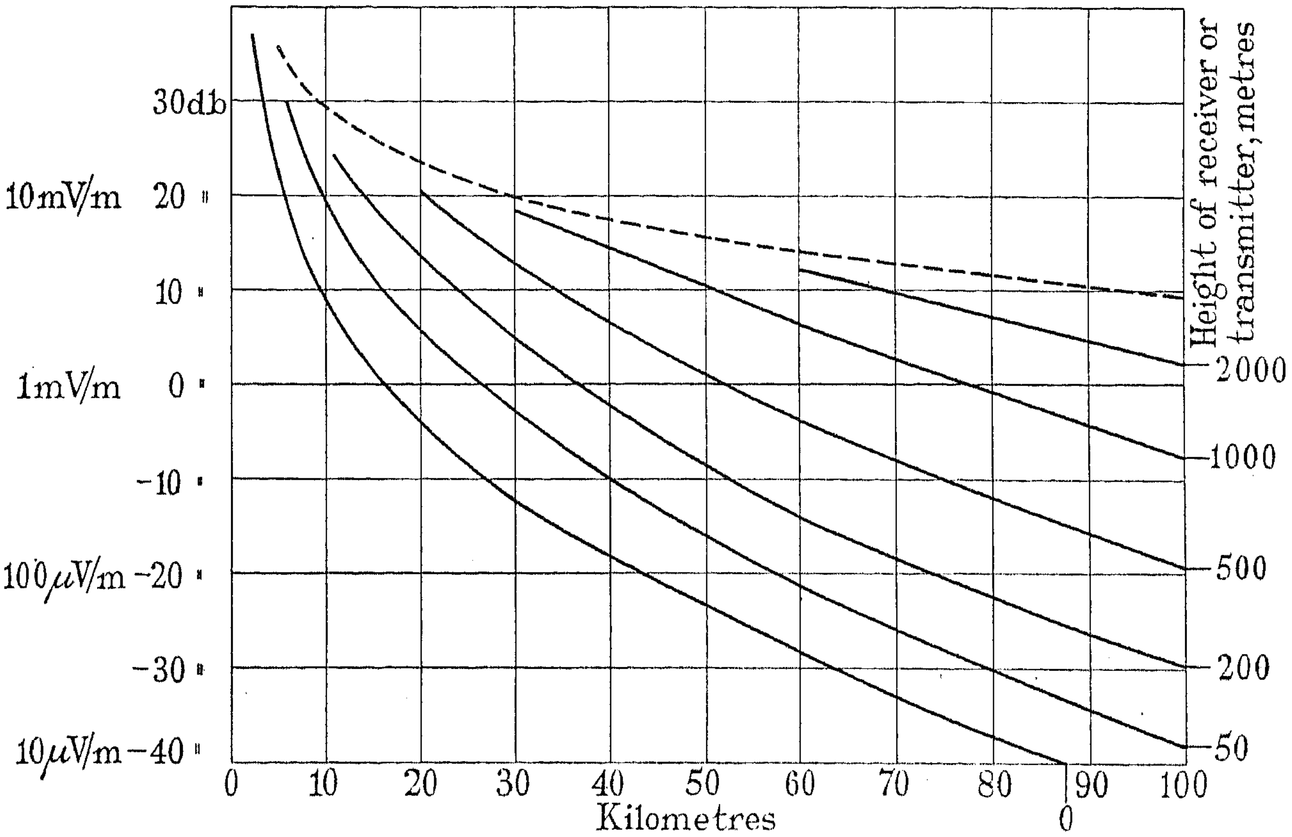

Fig. 14.—Results obtained over sea; $\lambda = 10$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

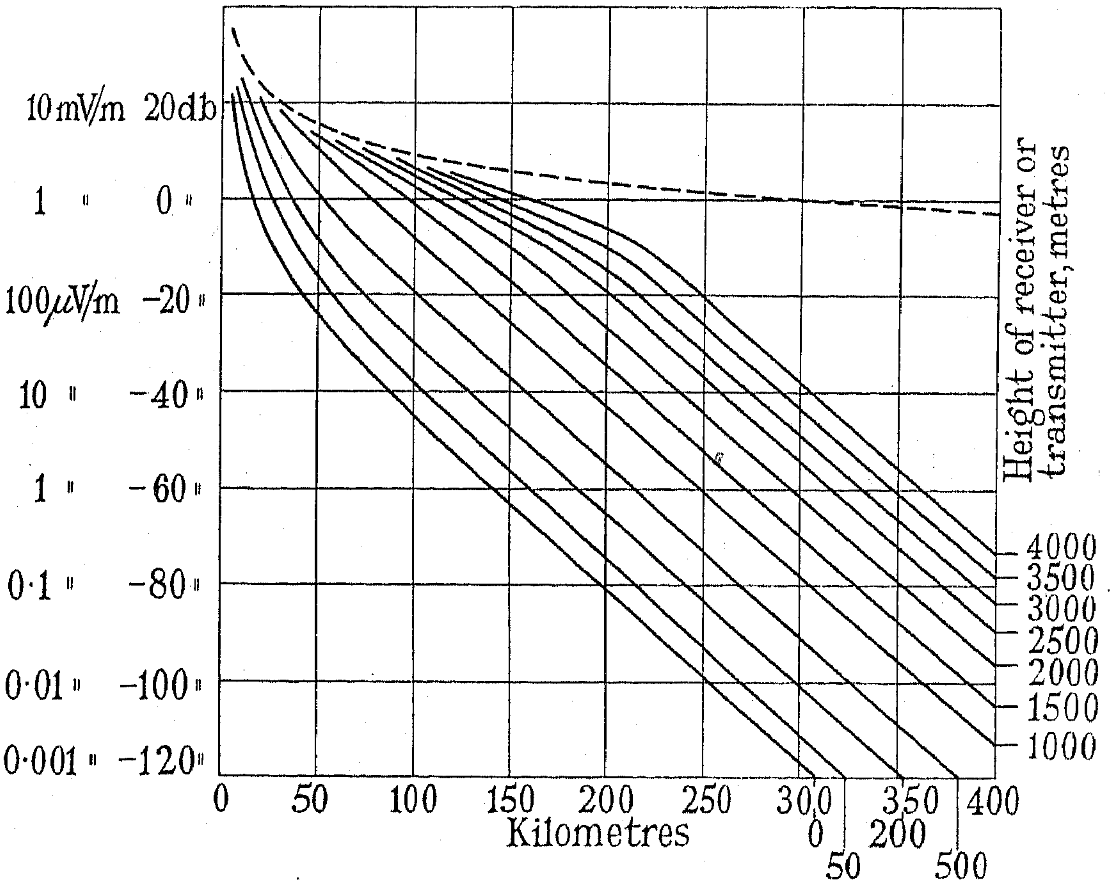

Fig. 15.—Results obtained over sea; $\lambda = 10$ m, $\kappa = 80$, $\sigma = 10^{-11}$, 1 kW radiated.

For heights less than about 500 metres, and distances less than 50 km but greater than about 3 km, the field at R is calculated as the resultant of the direct ray TR and the reflected ray TER [Fig. 28(*b*)]. The intensity is proportional to the inverse square of the distance. This follows from Sommerfeld's theory, or equally well from the approximate theory by which the larger-scale curves for distances up to 100 km are calculated in this manner, and the transition to the diffraction curves is reasonably well defined (see Fig. 29). These

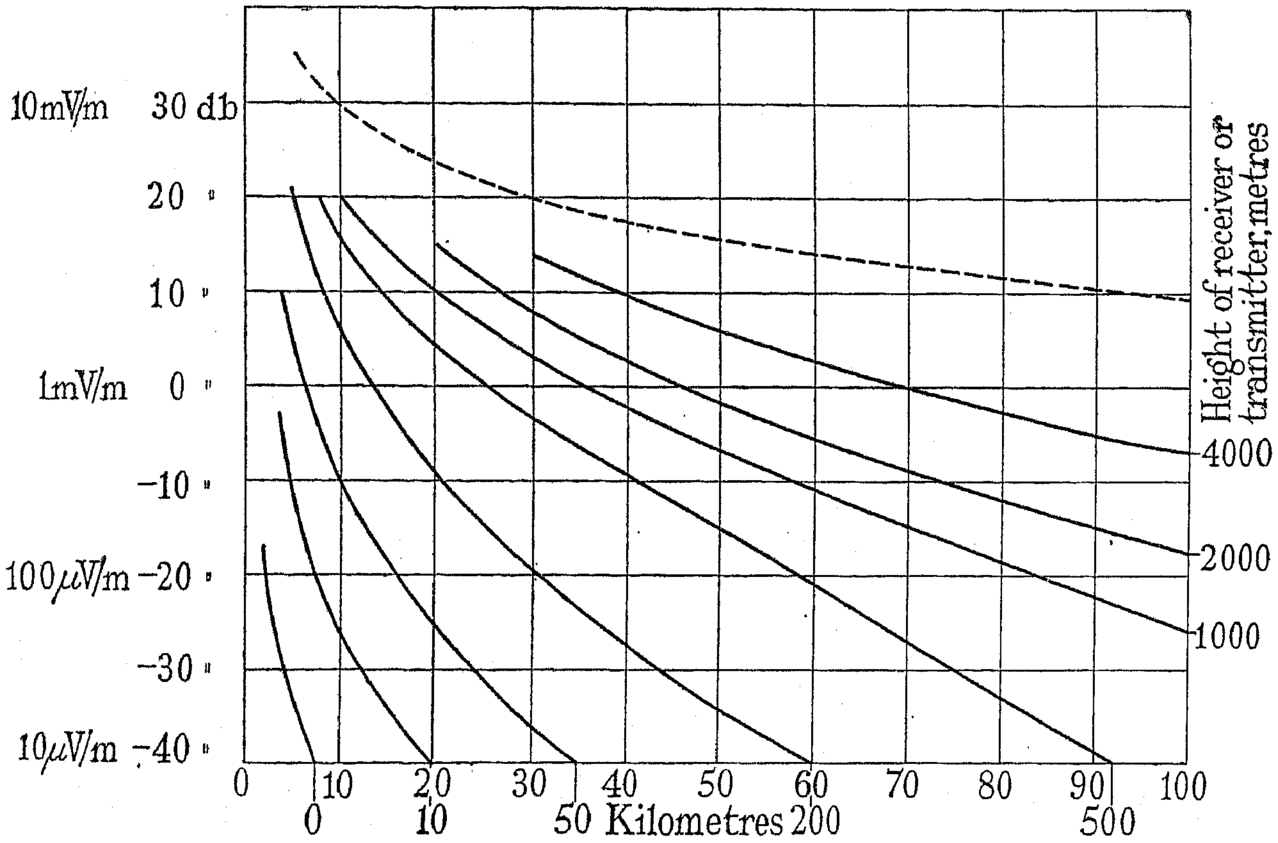

Fig. 16.—Results obtained over land; $\lambda = 2$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

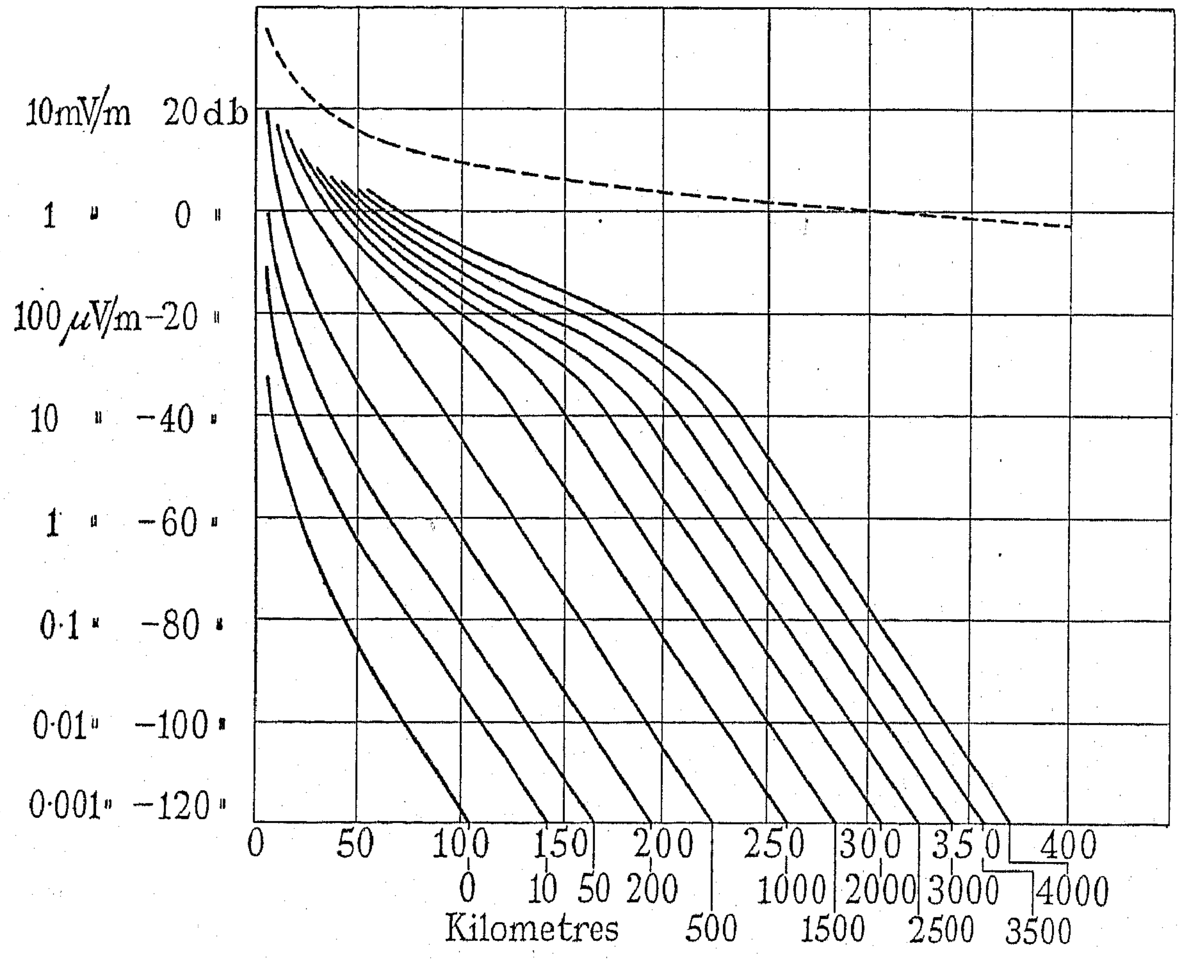

Fig. 17.—Results obtained over land; $\lambda = 2$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.
Figures against curves indicate height of receiver or transmitter in metres.

results have been recently checked experimentally,* but as long ago as January, 1925, the same law was determined experimentally in a 10-metre transmission in a range between 5 and 25 miles and correctly explained as a consequence of Sommerfeld's theory. Other experimental confirmations of these diffraction curves are given in C.C.I.R. Documents, Lisbon (vol. 1, Propositions, p. 1294), in which the measured attenuation is shown to agree closely with the calculated value. The theoretical gain in decibels as a function of the height has also been checked against the experimental autogyro results obtained by Trevor and Carter and by Jones, and good agreement found. The above experimental checks constitute a considerable body of evidence that, although

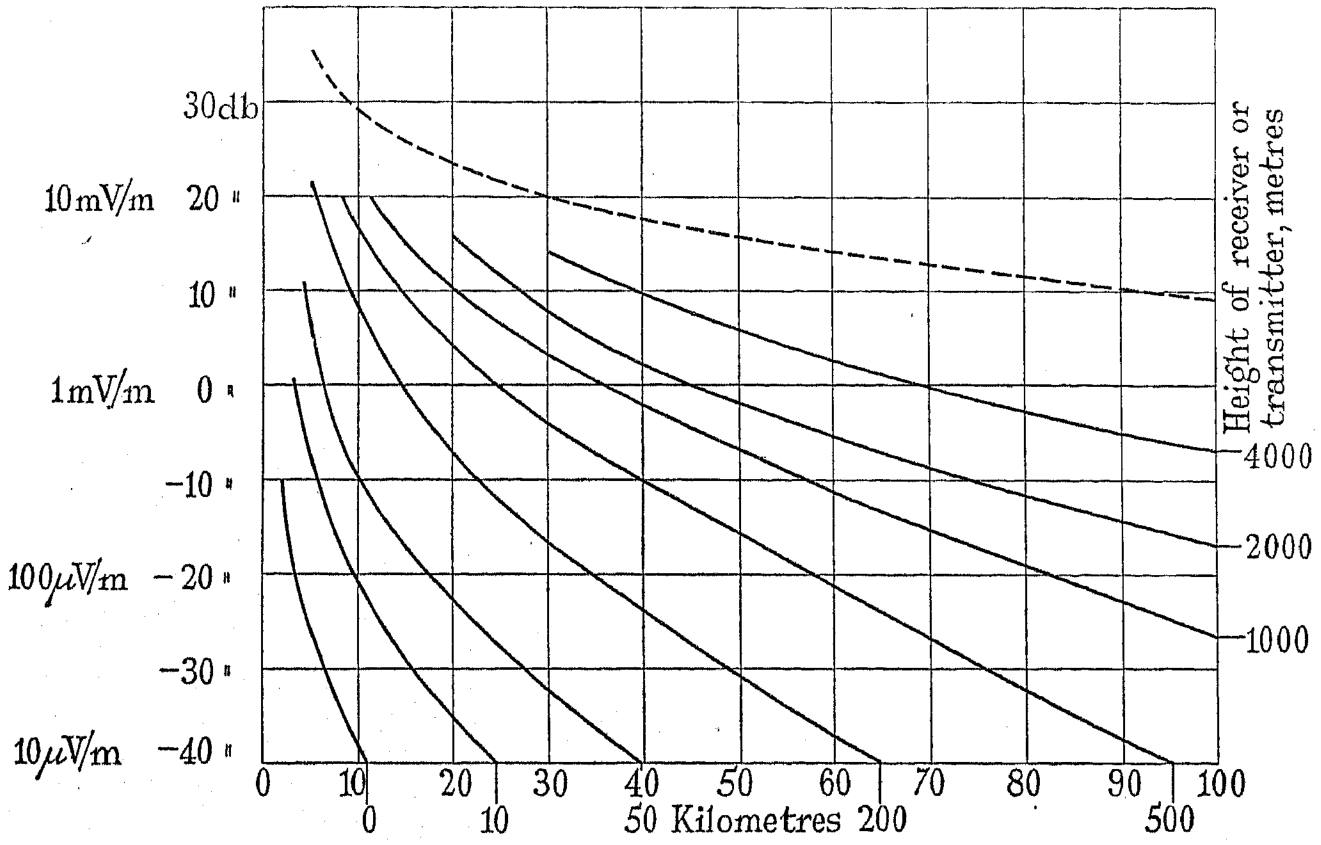

Fig. 18.—Results obtained over land; $\lambda = 4$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

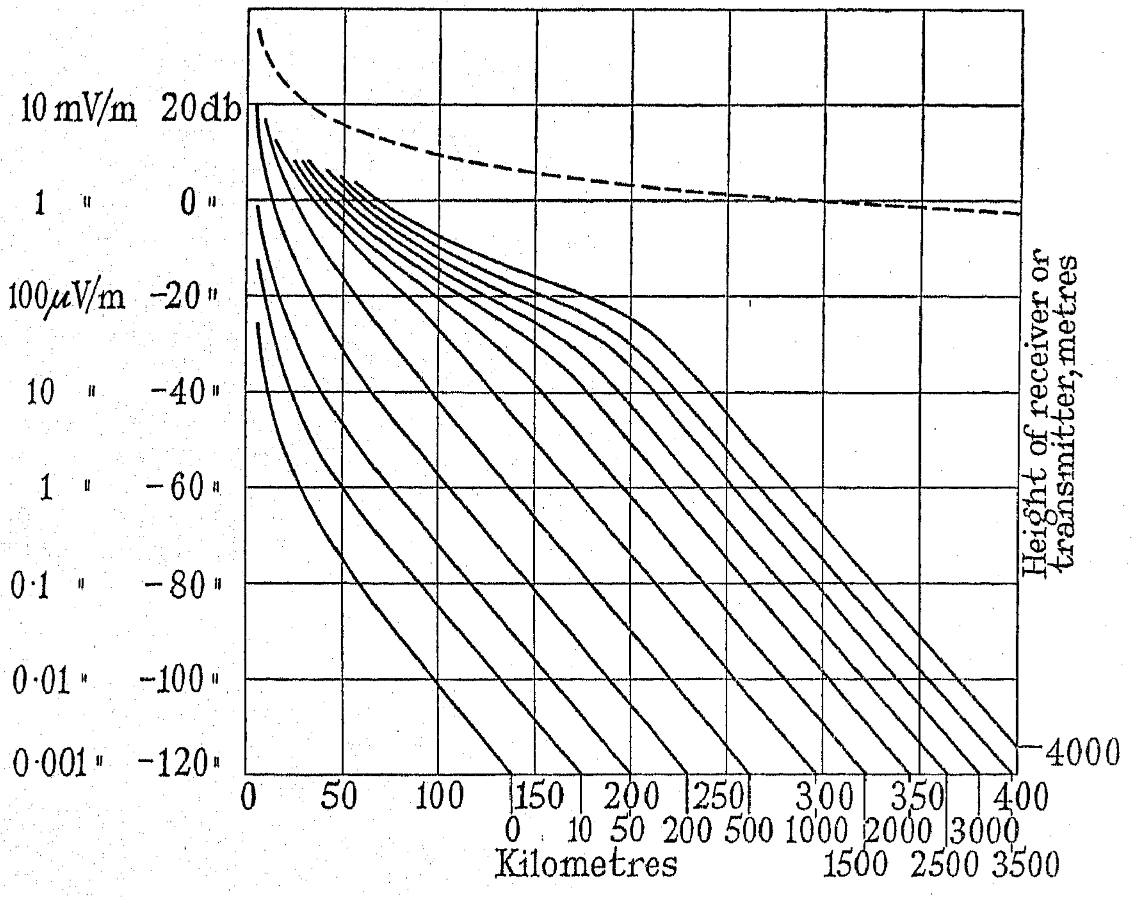

Fig. 19.—Results obtained over land; $\lambda = 4$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

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* B. Trevor and P. S. Carter: *Proceedings of the Institute of Radio Engineers*, 1933, vol. 21, p. 387; also C. R. Burrows, L. E. Hunt, and A. Decino: *Bell System Technical Journal*, 1935, vol. 14, p. 253.

fading at extreme distances may imply a small degree of refraction, the major part in ultra-short-wave transmission is played by diffraction.

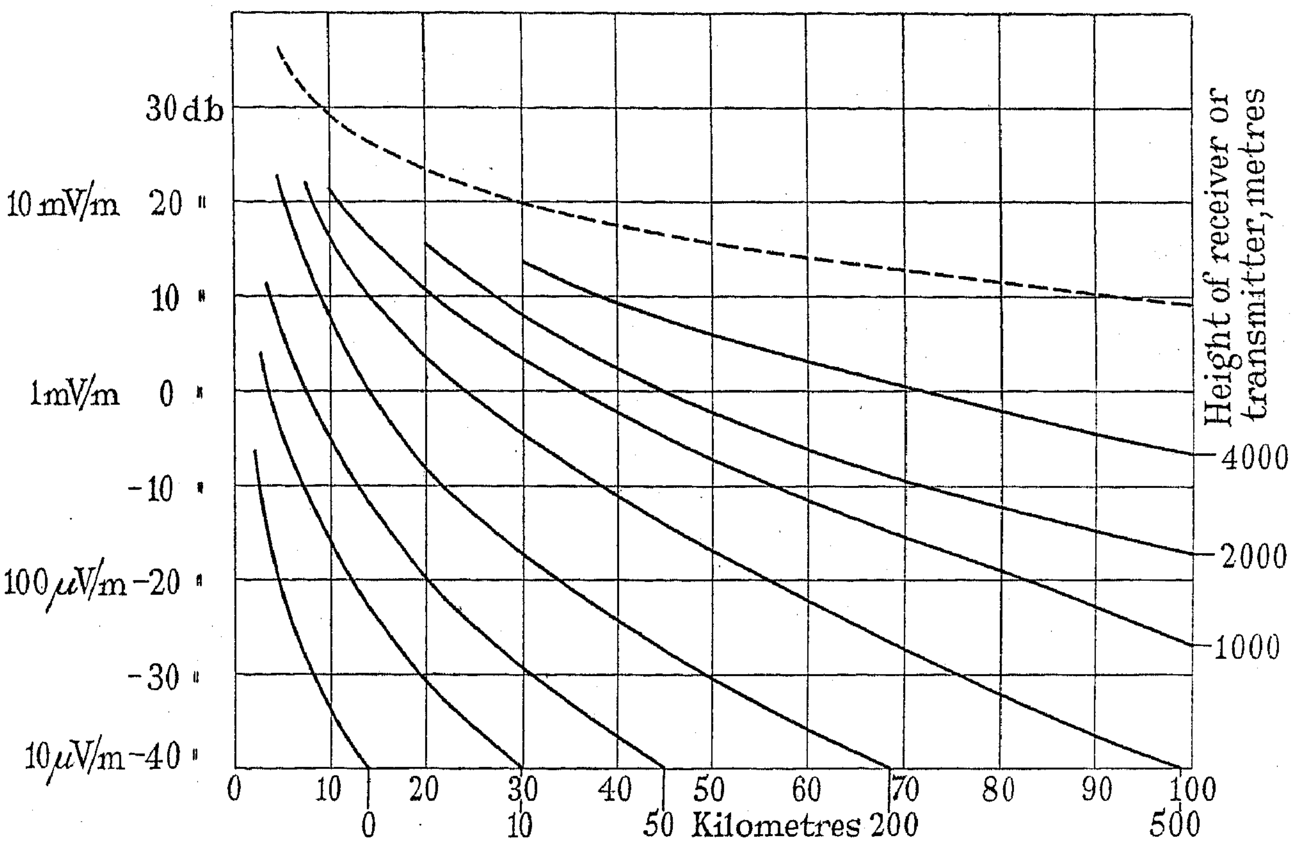

Fig. 20.—Results obtained over land; $\lambda = 6$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

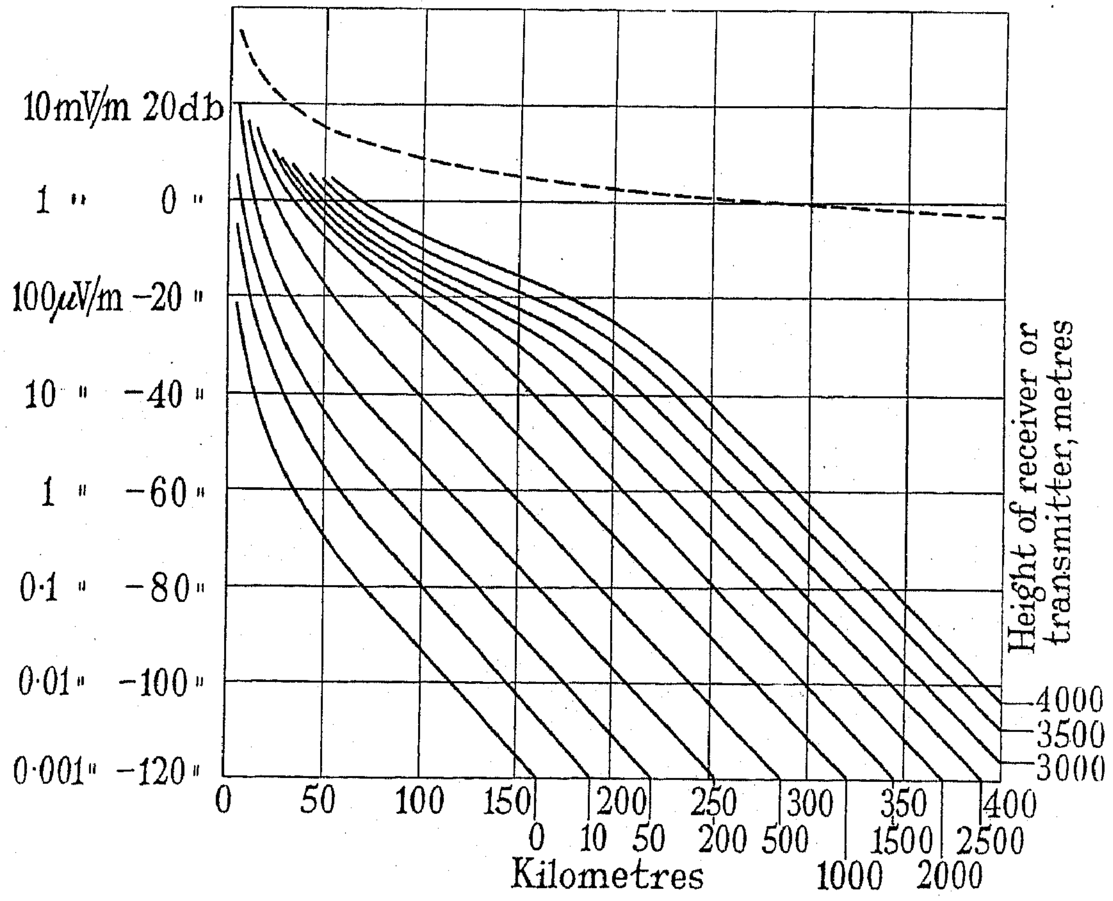

Fig. 21.—Results obtained over land; $\lambda = 6$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

REFRACTION

Although, as stated above, the major factor controlling ultra-short-wave propagation is diffraction, there is not wanting evidence of variation of signal intensity at extreme distances, which the author considers can only be caused by variation in the gradient of the refractive index of the air near the surface of the ground. The alternative hypothesis that the variations are due to reflections from the ionosphere seems very doubtful, for, although there is evidence of reflections at normal incidence of waves well above the critical frequency, the reflections occur in sporadic bursts and are very unlike the slow fadings observed in ultra-short-wave propagation. On the other hand the extreme ranges, recently recorded, of police-car signals on 9 metres from America, and television signals from Germany, are evidence of reflection from the ionosphere at glancing incidence.

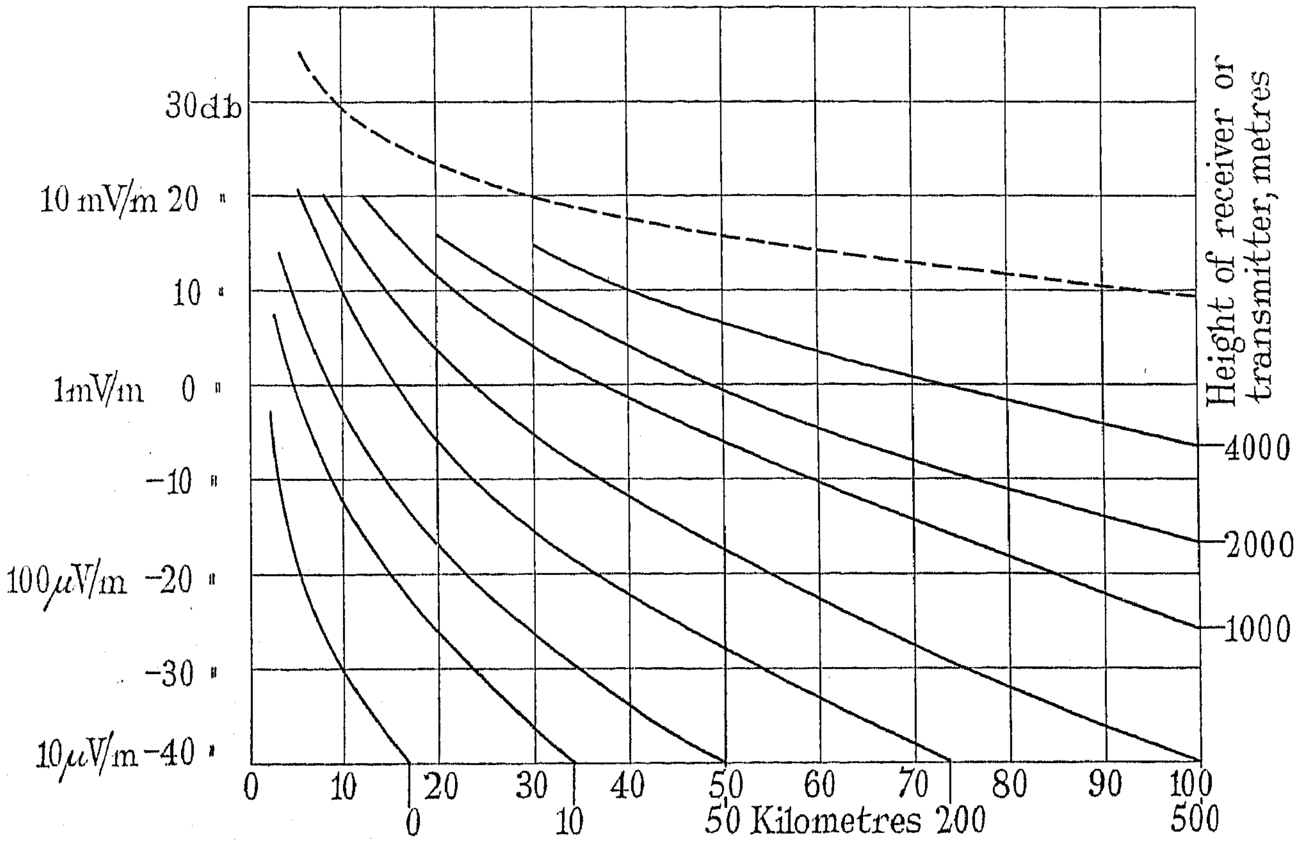

Fig. 22.—Results obtained over land; $\lambda = 8$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

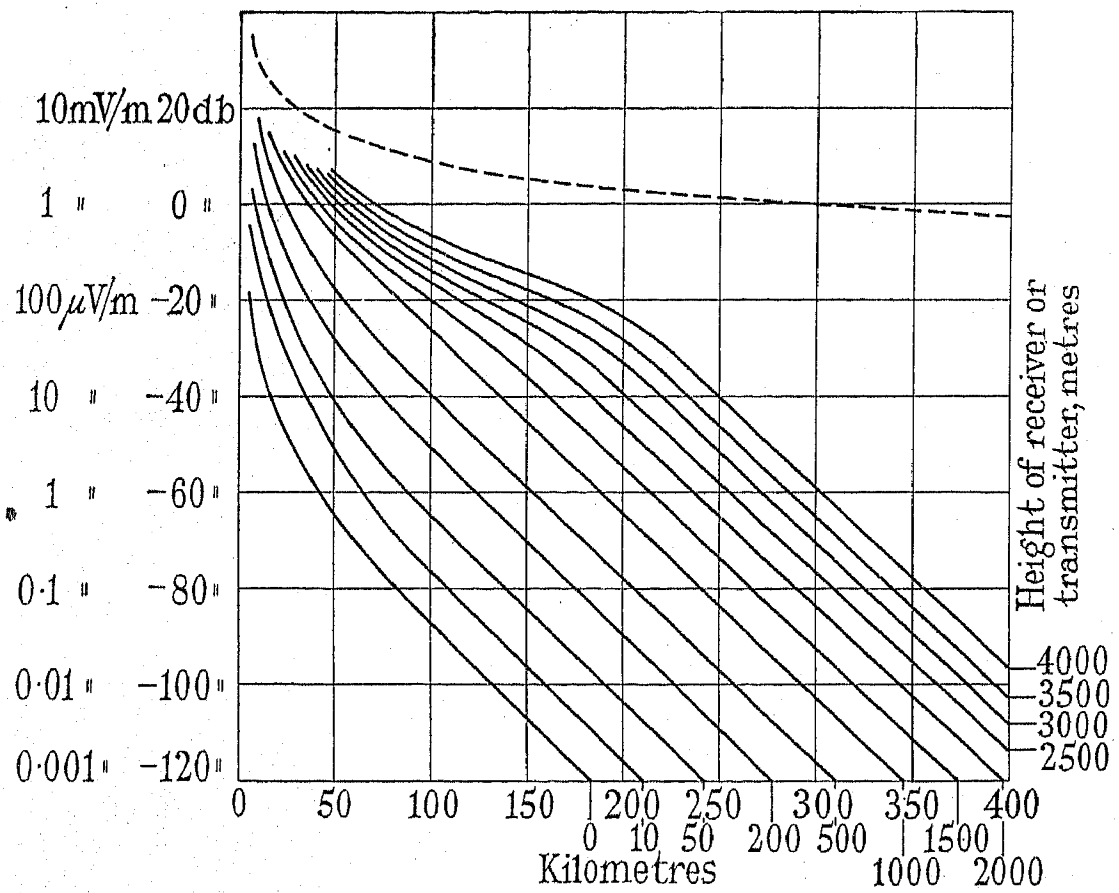

Fig. 23.—Results obtained over land; $\lambda = 8$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

These reflections are likely to occur at the upper limit of the ultra-short-wave band. With the approach of sun-spot maximum conditions, waves of this kind are likely to be propagated over long distances and so may interfere with local reception on these waves, but regular long-distance working with such waves will be impossible on account of unreliability. Waves below 10 metres will usually be too close to the limit to give reliable working.

This ultra-short-wave fading is of extreme importance from the practical point of view, for in general it sets a limit to the range of a service long before the average signals become too weak. Thus the study of ultra-short-wave propagation would be incomplete without an analysis of the effect of refraction. This is in the main not an optical ray problem, for diffraction lies outside the scope of such methods. If ray methods are used, they require justification by a more complete wave analysis. Fortunately the wave method, by which the diffraction curves above were calculated, allows an easy extension to the case where the atmosphere above the earth has a vertical gradient of refractive index.

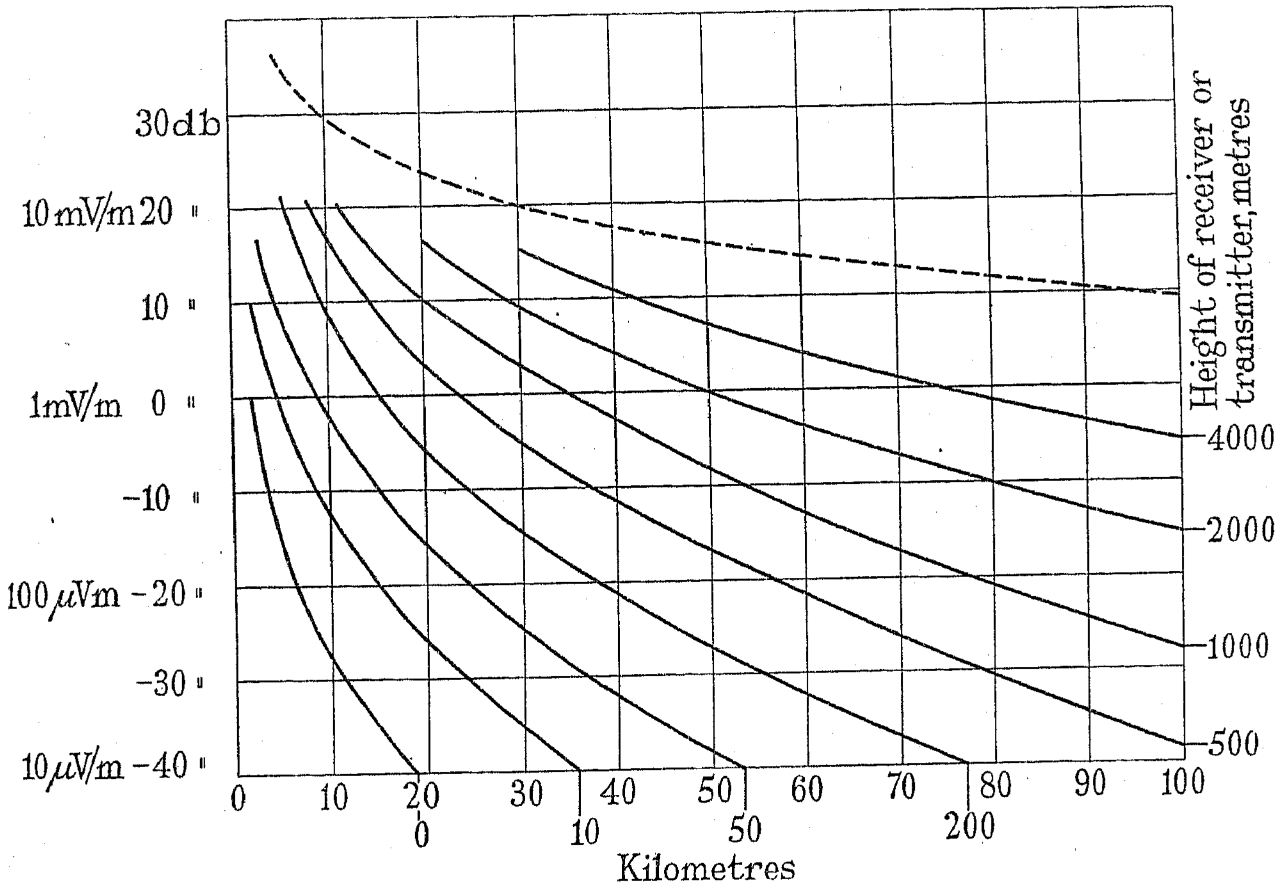

Fig. 24.—Results obtained over land; $\lambda = 10$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

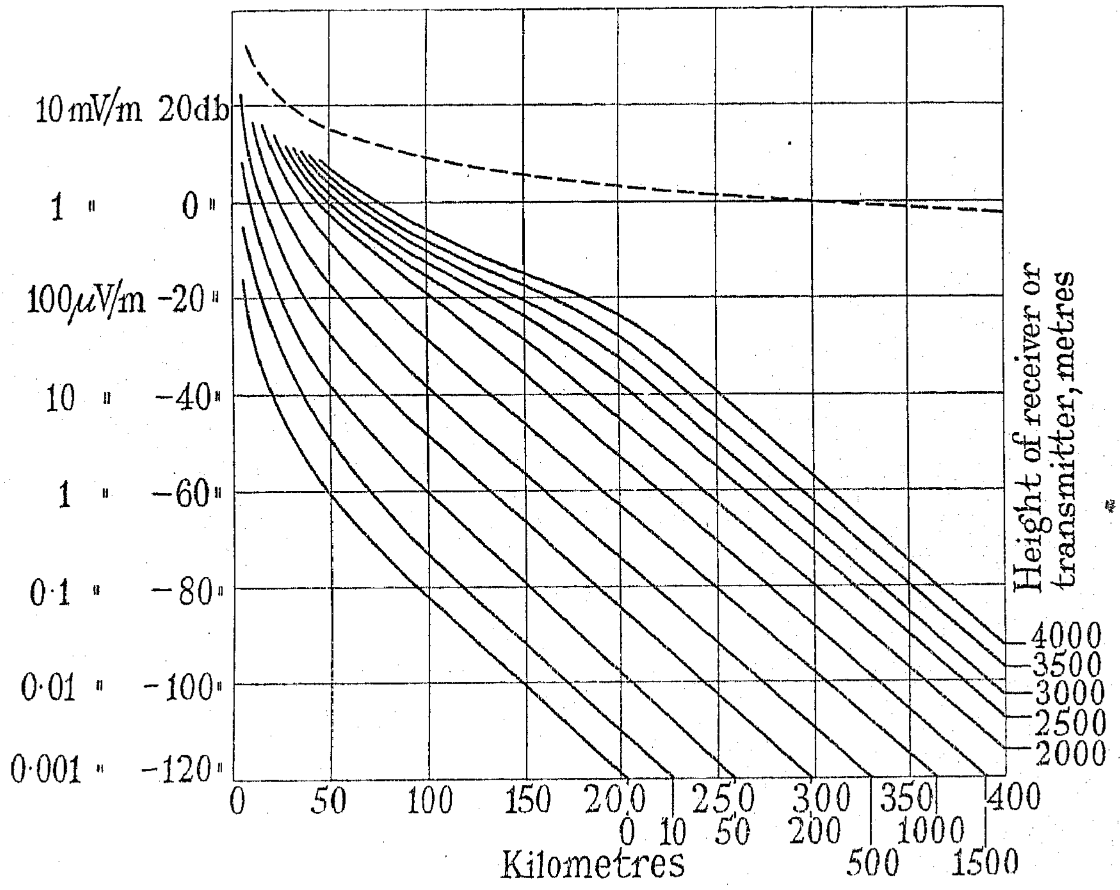

Fig. 25.—Results obtained over land; $\lambda = 10$ m, $\kappa = 5$, $\sigma = 10^{-13}$, 1 kW radiated.

The field intensity beyond the visual distance, where fading is in evidence, can be expressed in the form

$$Ae^{\frac{-(2\pi)^{\frac{1}{3}}\beta_n d}{R^{\frac{2}{3}}\lambda^{\frac{1}{3}}}}$$

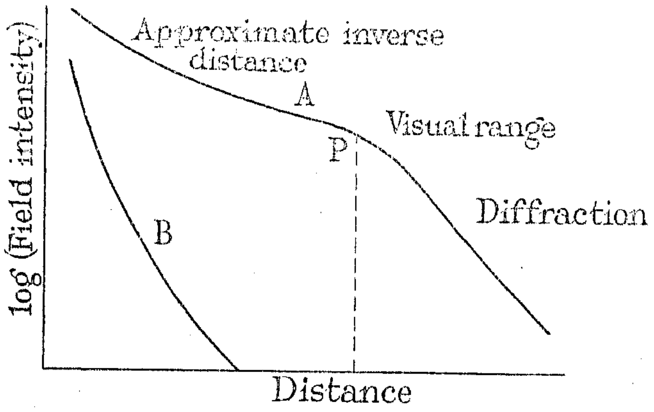

Fig. 26

where β_n is a constant determined in the diffraction analysis, d is the distance, and R_0 is the earth's radius. The field intensity is mainly controlled by the exponential e^{-kd}. A is the amplitude factor, similar to the factor $\frac{0\cdot5386hI}{\lambda^{\frac{7}{6}}\sin^{\frac{1}{2}}\theta}$ in Van der Pol's diffraction formula, and modified by a factor γ ($<$ 1) which takes account of the earth constant. It is only a very slowly varying function of distance.

Assuming a practically uniform gradient in the atmosphere, which would be a natural consequence of the upward decrease in molecular density in the atmosphere, it is found that the effect of this gradient is to modify the exponential coefficient by substituting an equivalent earth's radius R_0' for R_0, where

$$R_0' = R_0\frac{R_1}{R_1 - R_0}$$

The distance R_1, which depends on the gradient of refractive index (μ) being $\frac{1}{\mu}\frac{\delta\mu}{\delta h}$, is readily interpreted as the radius of curvature of the ray caused by the vertical gradient of the refractive index.

The physical meaning of the modification to the diffraction formula is now apparent. The circumstances are illustrated in Fig. 30(a), where TS is the earth's surface and TR is the tangent ray, curved downwards by the effect of the gradient of refractive index in the atmosphere above the earth's surface. If we now make a mathematical transformation such that any radius r becomes $r[R_1/(R_1 - r)]$, the radius of curvature of TR, where $r = R_1$, becomes infinite, and that of the earth $R_0R_1/(R_1 - R_0)$. In the transformed space the ray TR is a straight line T_1R_1 [Fig. 30(b)], and the earth's radius is increased from R_0 to $R_0R_1/(R_1 - R_0)$.

The problem of propagation in the transformed space is now one in which there is no effective gradient of refractive index outside the earth (T_1R_1 being a straight line), and the solution is the same as that previously given, with R_0' in place of R_0. Shelleng, Burrows, and Ferrell have employed this method for determining the effect of refraction, using an argument similar to the above.

It can now be seen that this argument is justified from the wave point of view. It should be noted, however, that the coefficient A should also be changed, but this change is small so long as R' is considerably greater than R_0, as is usually the case. The change in A cannot be allowed for by putting R_0' in the place of R_0.

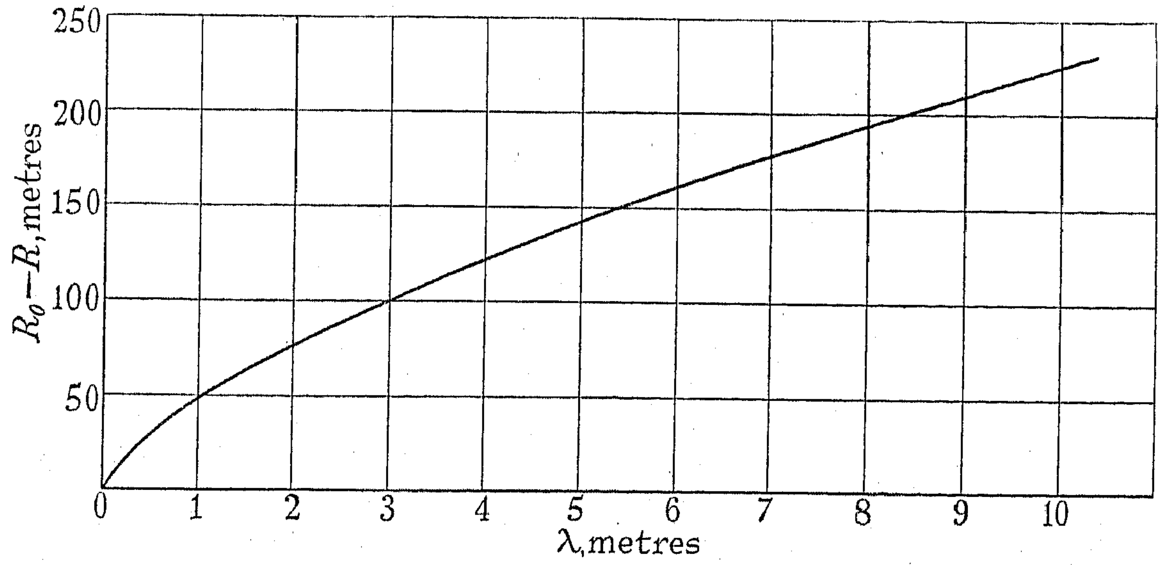

Fig. 27.—Values of R_0—R.

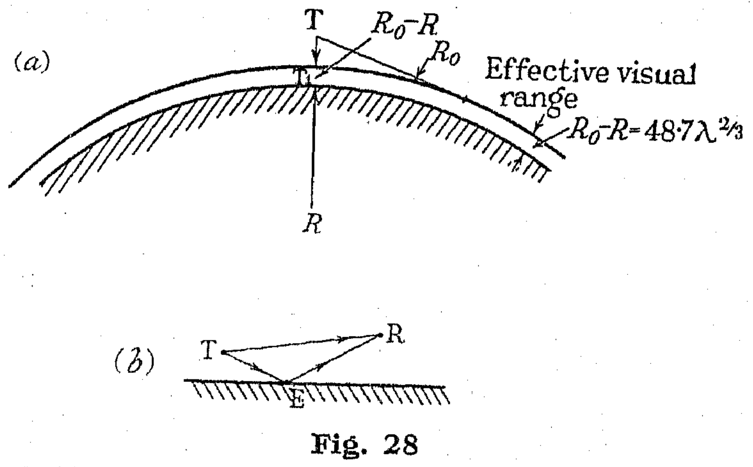

Fig. 28

In (a), T_1 has no effective visual range. λ is expressed in metres.

One point is significant in the analysis: it appears that it is mainly, if not entirely, the gradient of the refractive index in the first few hundred metres which

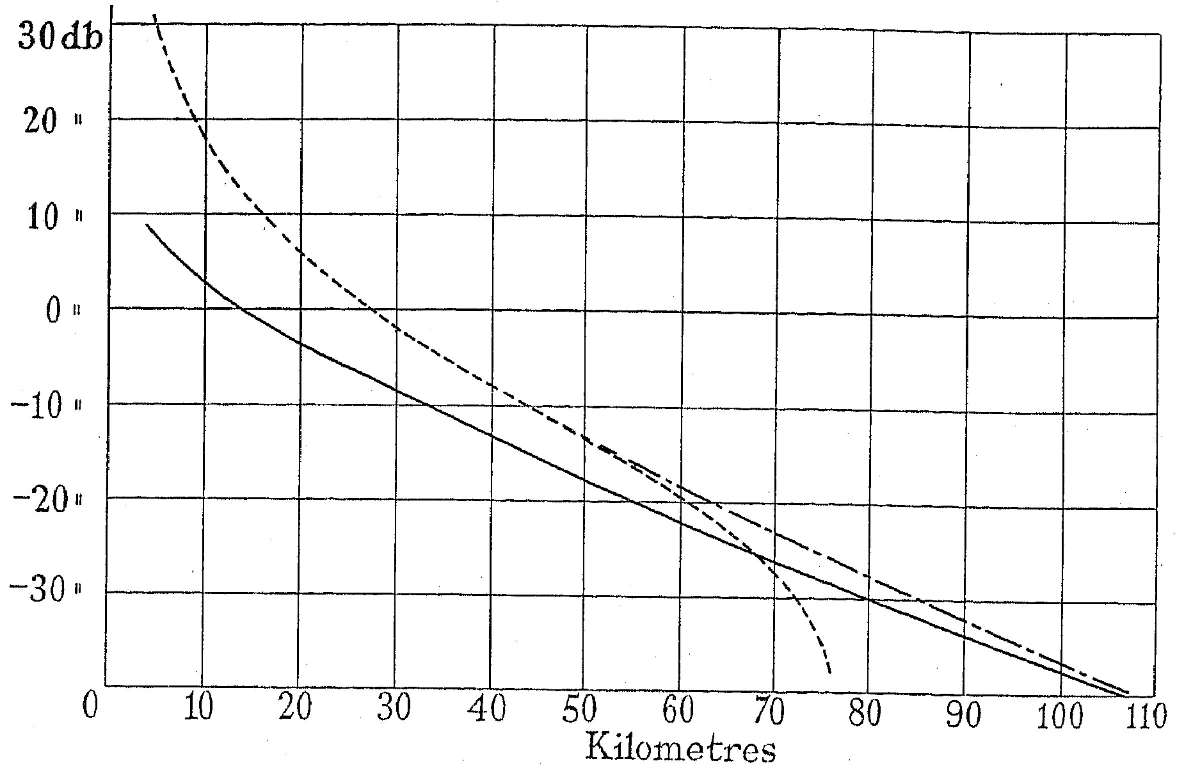

Fig. 29.—Continuity of reciprocal and diffraction values: results obtained over land, $\lambda = 10$ m, $h = 500$ m.

— — — — Reciprocal theorem.
———— Diffraction theory.

counts, at least as far as transmission from one point on the ground to another on the ground is concerned.

The magnitude of the refraction effects depends on the gradient of the refractive index of the atmosphere. The refractive index of air is well known, and is proportional to the density. Since the density decreases upwards in the atmosphere there is a vertical gradient of μ which can be computed when the pressure gradient is known. Water vapour has a high refractive index, and the effect of a small percentage is very pronounced.* The relative refractive indexes of air and water vapour are given in the following table:—

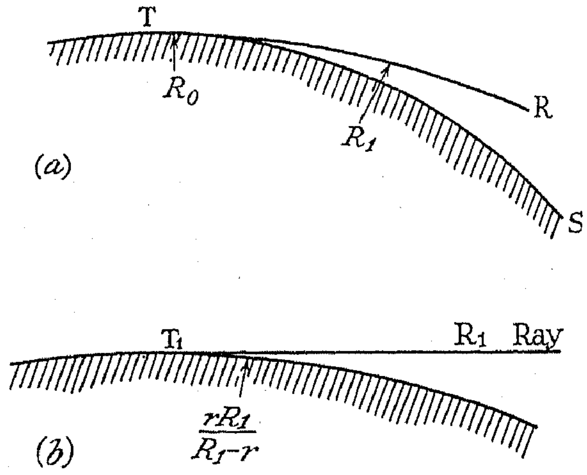

Fig. 30

(a) Actual space.
(b) Transformed space.

Temperature	μ (air)	μ (water vapour)
45° C.	1·000574	1·01033
63° C.	1·000554	1·00965
83° C.	1·000534	1·00898

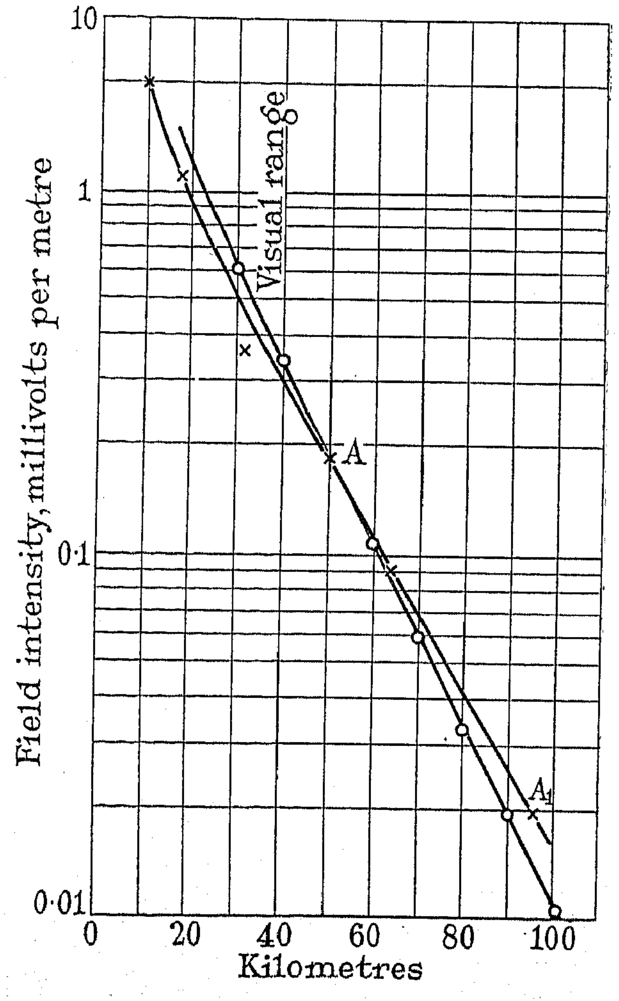

Fig. 31.—Ultra-short-wave diffraction. Results obtained by Jones at 61 megacycles per sec., in transmission from Empire State Building, New York.

The diffraction curve is adjusted to fit at A.
× × Observed field intensity.
o o Calculated relative field intensity.

The difference of μ from 1 in water vapour is nearly 20 times as great as that for air, so that the effect of even a small percentage of water vapour is very considerable.

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* The relevant data can be found in a paper by C. R. Englund, A. B. Crawford, and W. W. Mumford: "Further Results of a Study of Ultra-Short-Wave Transmission Phenomena," *Bell System Technical Journal*, 1935, vol. 14, p. 383. Further data may be obtained from Humphrey's "Physics of the Air," and from an article on "The Thermodynamics of the Atmosphere" in the "Dictionary of Applied Physics" (vol. 3, p. 44). The diagram on p. 61 of the latter is of particular interest, as it shows the large increase of saturated water-vapour density in summer as compared with winter.

Englund, Crawford, and Mumford have given the following formula for calculating R_1:—

$$R_1 = \frac{M \times 10^6}{31\,185} \times \frac{1}{\frac{\delta}{\delta h}\left\{\beta\left[211 + \alpha\left(\frac{10\,159}{\tau} - 0\cdot293\right)\right]\right\}}$$

where M is the molecular weight of the gas involved, α the percentage of water vapour, τ the absolute temperature, and h the height. A typical numerical example has been worked out for average conditions on the surface of the earth, with 1·37 per cent water vapour, giving $R' = 23\,000$ km. In the absence of the 1·37 per cent of water vapour, R' would be 39 000 km. In the former case the increase in range at which a given field intensity occurs is

$$\left(\frac{R'_0}{R_0}\right)^{\frac{2}{3}} = \left(\frac{R_1}{R_1 - R_0}\right)^{\frac{2}{3}} = \left(\frac{23\,000}{23\,000 - 6\,360}\right)^{\frac{2}{3}} = 1\cdot274$$

i.e a 27·4 per cent increase. In the latter case the increase is $[39\,000/(39\,000 - 6\,360)]^{\frac{2}{3}}$, i.e. 14·2 per cent.

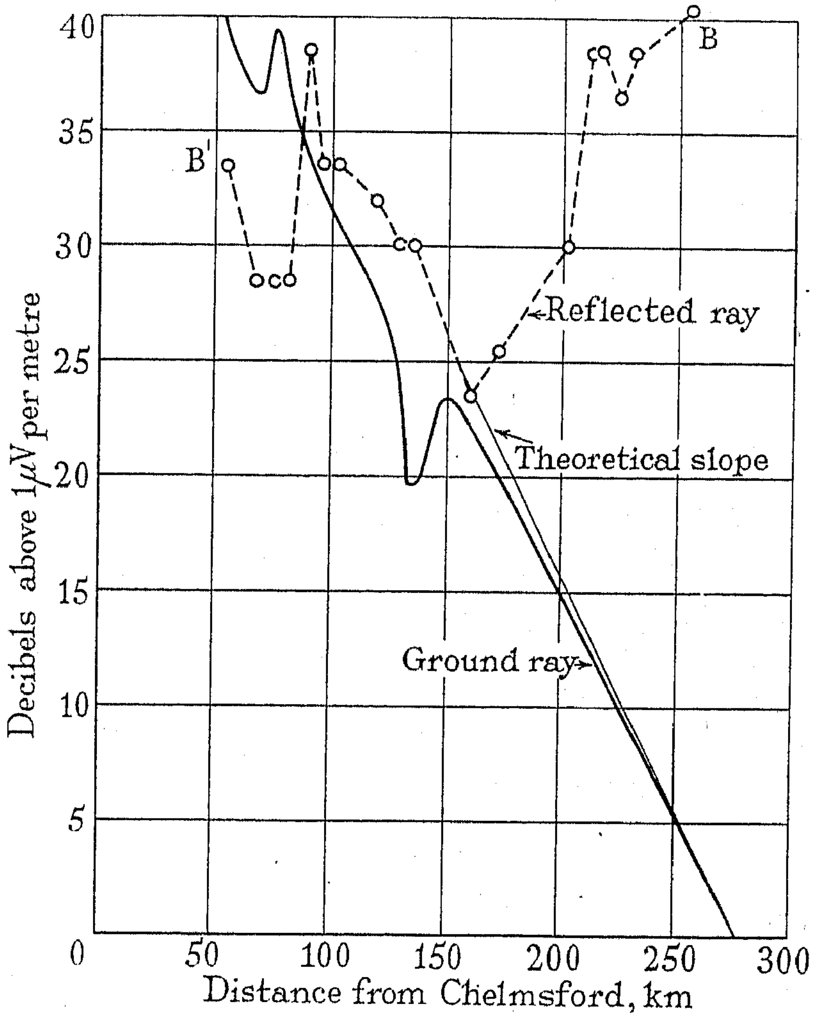

Fig. 32.—Aeroplane test. Results obtained on wavelength of 53·4 m, 1st October, 1935.

These considerations, taking into account the considerable increase in water-vapour density in the summer, give a very plausible explanation of the now well-established result that the signal-intensity values well beyond the visual distance are much greater in summer than in winter. The effect of refraction is to increase the range, especially when, for instance, there are temperature inversions at the surface of the earth.

The varying refractive index of the atmosphere is probably the cause of the fading observed at extreme distances, which limits the reliable range. A given percentage variation in the gradient will produce a much greater percentage effect where the total attenuation is large than where it is small. Serious fading will therefore set in at ranges where the total attenuation is large. It must be left to observation to determine how large, but from the limited results obtained by Englund, Crawford, and Mumford it is suggested that an attenuation of about 30 db below the "free-space field" or inverse distance is reasonable.

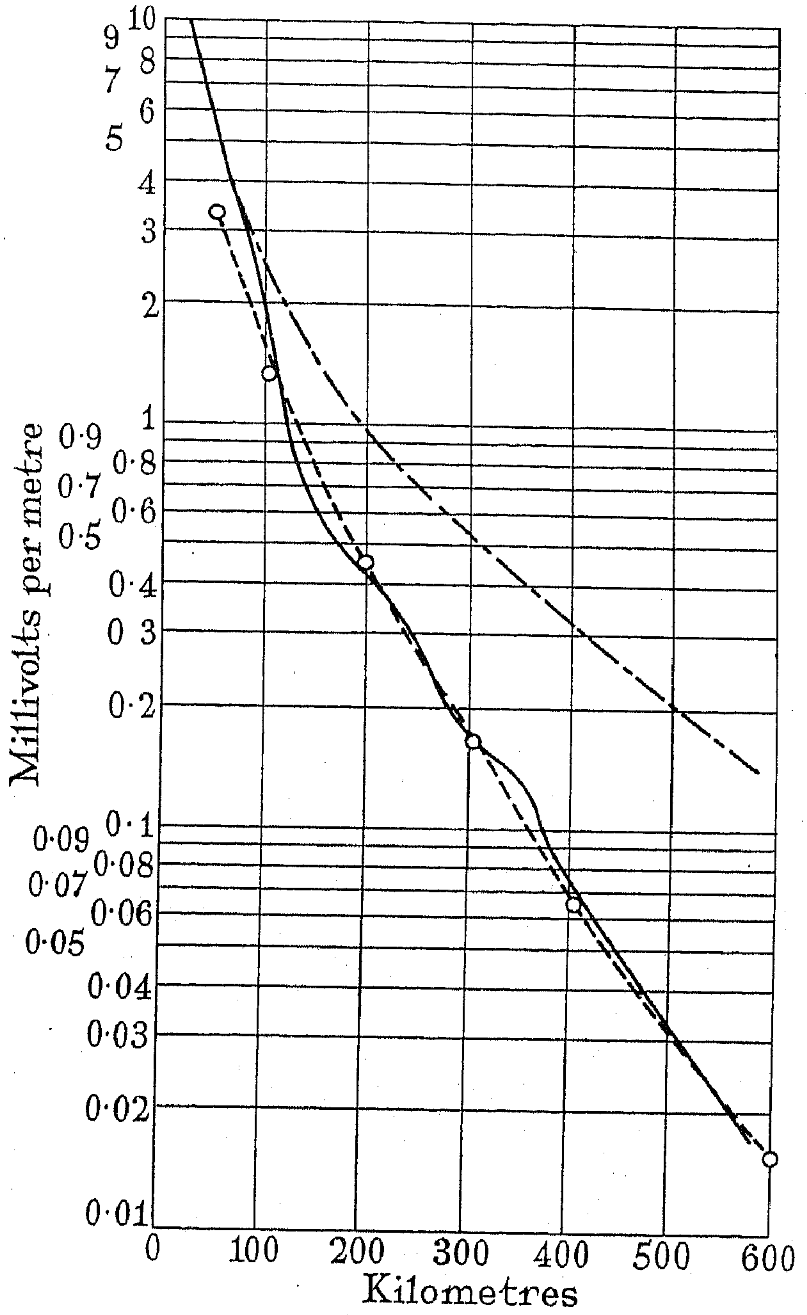

Fig. 33.—Aeroplane test. Results obtained on wavelength of 950 m.

— — — — Diffraction curve.
———— Observed values (Fassbender, Eisner, and Kurlbaum).
— - — - Sommerfeld curve.

EXPERIMENTAL CHECKS OF DIFFRACTION FORMULA FOR VARIOUS WAVELENGTHS

It is very desirable to check, experimentally, the theoretical conclusions discussed above, if only for the purpose of finding out whether there are important factors in ultra-short-wave transmission, e.g. lower-atmosphere refractions, other than those taken into account in the main analysis.

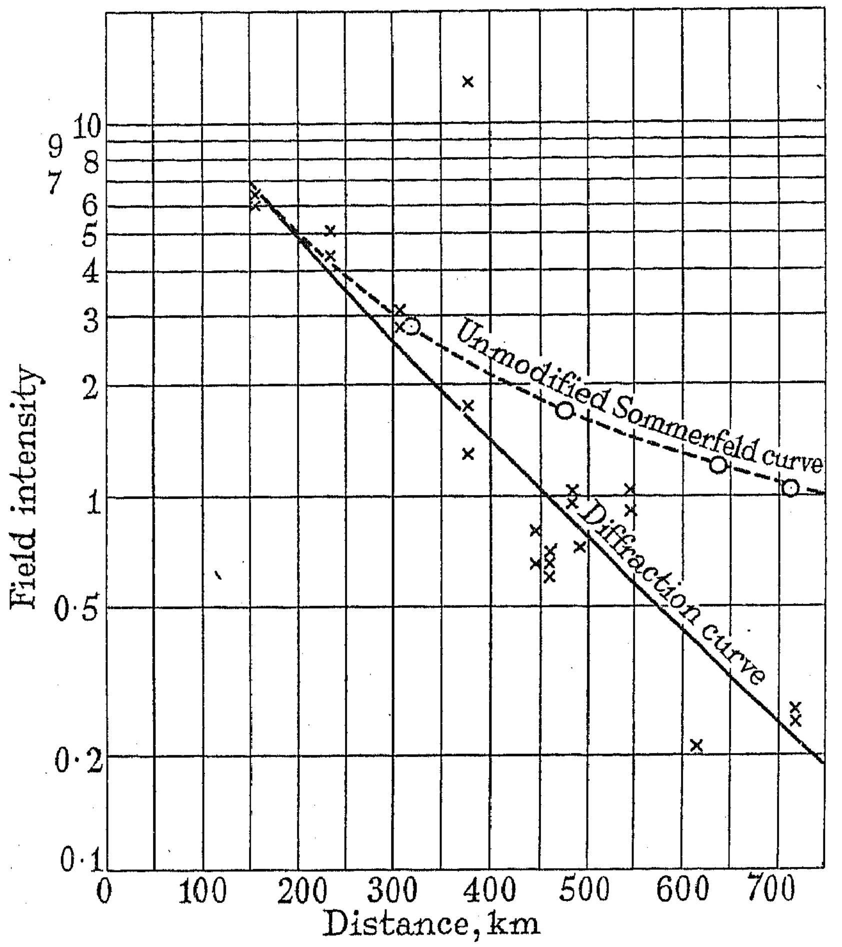

Fig. 34.—Daylight field strength of Daventry 5XX. Results obtained at midday, July, 1931; $\lambda = 1\,550$ m; normal power (25 kW).

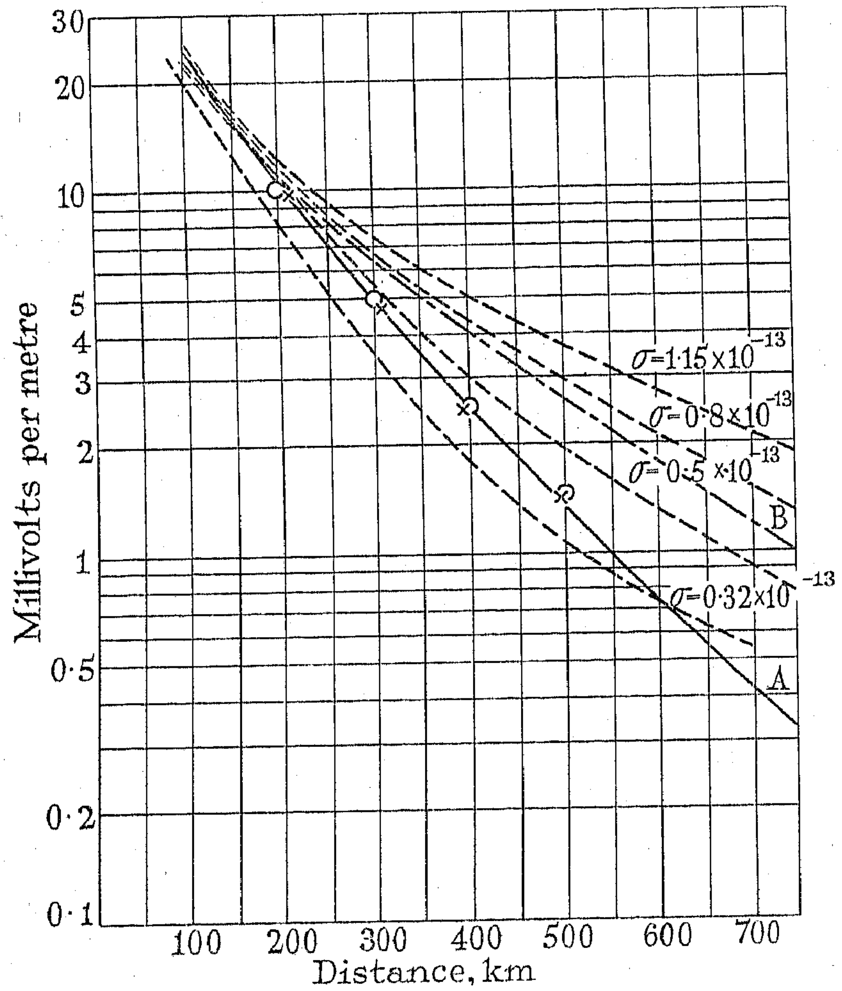

Fig. 35.—Results obtained on Warsaw; $\lambda = 1\,400$ m, 100 kW radiated.

A × Observed results.
A ⊙ Modified diffraction formula, $\sigma = 1{\cdot}15 \times 10^{-13}$.
B —— Original Watson diffraction formula.
– – – – – Sommerfeld formula.

In choosing the quantities to be compared with experimental observations it is desirable to leave out those which depend on the absolute amount of power radiated by the transmitter, since, in general, there is considerable difficulty in determining this quantity accurately. Relative, but not absolute, intensities can be checked fairly well. For the purposes of comparison use is made of the slope of the curve relating the logarithm of the field intensity to the distance, to compare with the calculated slope. Experimental data can be obtained from American results.*

An example is shown here (Fig. 31) in which AA_1 is the average curve of a large amount of data obtained by Jones in experimental transmissions from the Empire State Building, New York, on a frequency of 61 Mc. The observed rate of attenuation (or slope) is some 14 per cent less than the calculated; this difference may be due to atmospheric refraction. In the case of a normal atmospheric distribution of air density, when the effect of water vapour is neglected, the attenuation slope should be reduced approximately 15 per cent.

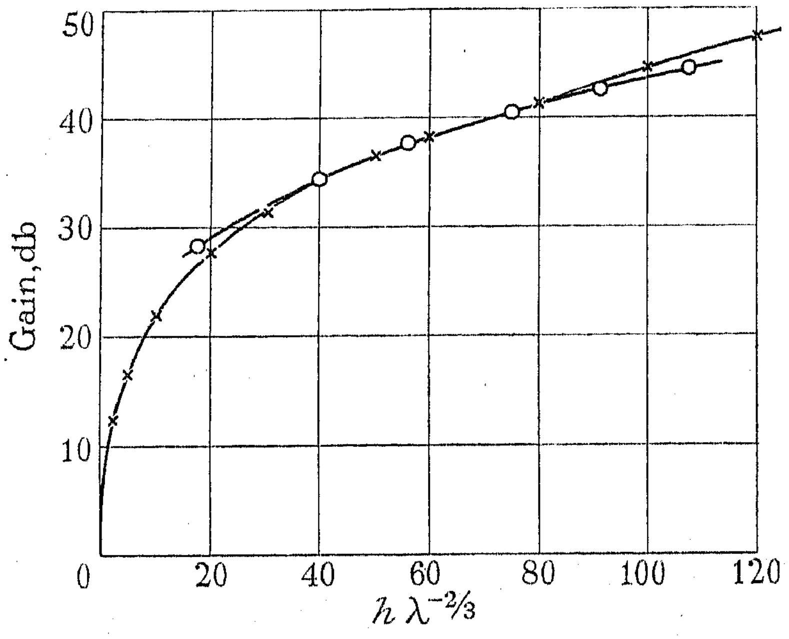

Fig. 36.—Height/gain observations. Results obtained by Jones at 44 megacycles per sec., in transmission to distance of 102 km from Empire State Building, New York. Height of transmitting aerial, 396 m.

× Calculated relative gain.
o Observed relative gain.

Another example is shown in Fig. 32, which represents the ground-ray intensity from a 53·4-metre transmitter in an aeroplane flight from Croydon to Cologne. Beyond 150 km, the visual range, the slope of the log (field)/distance curve is constant and agrees closely with the slope calculated according to the diffraction theory. The measurement of the ground ray at these distances, where the reflected ray was generally predominant, was made possible by means of the impulse technique, in which the ground ray was separated from the reflected ray by an interval of about 2 milliseconds.

To illustrate the scope of the diffraction theory the following examples on medium waves are given.

Fig. 33 gives an example for 950 metres, and consists of field measurements of medium-wave transmissions from an aeroplane. The experimental curve is compared with (*a*) the diffraction curve ($\sigma = 7 \cdot 5 \times 10^{-14}$), and (*b*) the Sommerfeld curve ($\sigma = 7 \cdot 1 \times 10^{-14}$). The agreement with the former is very good.

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* *Proceedings of the Institute of Radio Engineers*, 1933, vol. 21, pp. 349–464.

better agreement with the results than the Sommerfeld curve. The scattered observations are probably caused by the hilly country in which the measurements were taken, i.e. North England and Scotland. Finally, the Warsaw results (Fig. 35) show very good agreement with the diffraction values. The country is flat, and the observed curve is a smooth one agreeing closely with the calculated curve for $\sigma = 1 \cdot 15 \times 10^{-13}$.

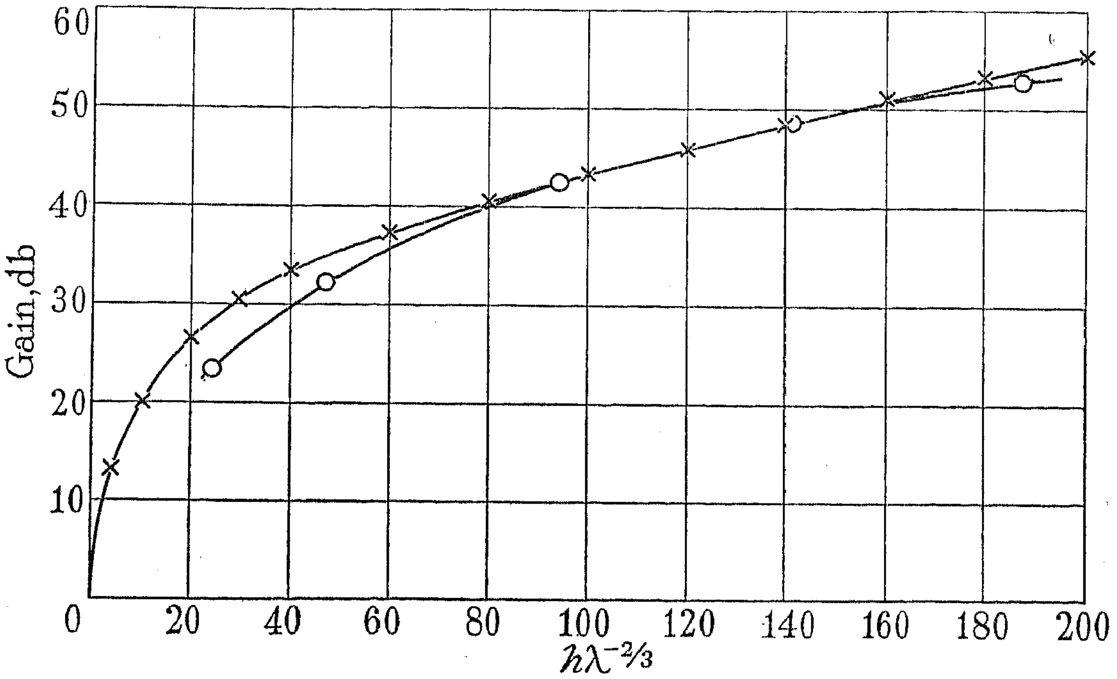

Fig. 37.—Height/gain observations. Results obtained by Trevor and Carter at 34 megacycles per sec., in transmission to distance of 59·6 km from Rocky Point. Height of transmitting aerial, 39 m.

× Calculated relative gain.
o Observed relative gain.

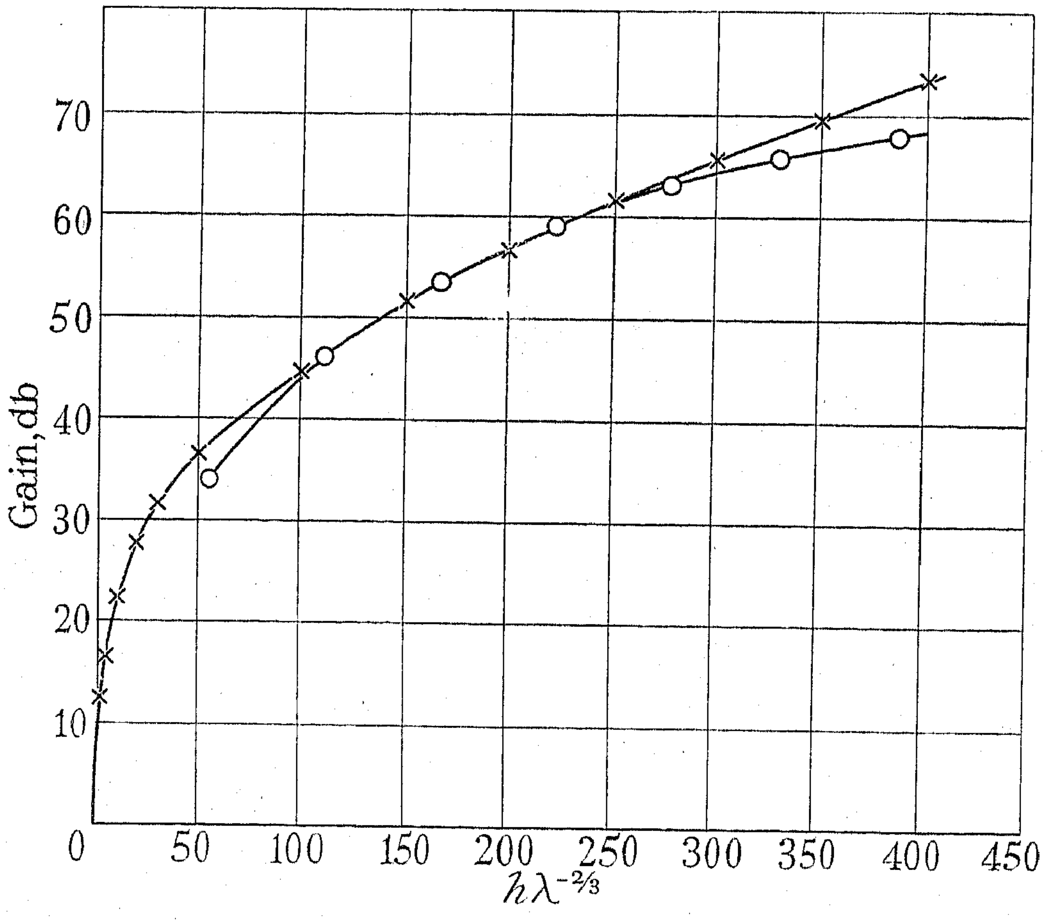

Fig. 38.—Height/gain observations. Results obtained by Trevor and Carter at 44 megacycles per sec., in transmission to distance of 185 km from Empire State Building, New York.

× Calculated relative gain.
o Observed relative gain.

In Figs. 34 and 35, measured values of Daventry and Warsaw are compared with the diffraction values. In the case of Daventry the points fall rather irregularly, but there is no doubt that the diffraction curve is in

With regard to the examples shown in Figs. 31 and 32, it should be emphasized that the calculated results do not involve any arbitrarily-assumed earth conductivity or permittivity. The calculated attenuation depends only on the wavelength (and, of course, the earth's radius) so long as the wavelength is so short that

$$\sigma^{\frac{1}{2}}\lambda^{\frac{5}{6}} < 10^{-7}$$

Even with sea water this condition is satisfied, and in every case of overland transmission the quantity $\sigma^{\frac{1}{2}}\lambda^{\frac{5}{6}}$ should be well below the limiting value. The reason for this is that in the diffraction attenuation factor $e^{-kd/\lambda^{\frac{1}{3}}}$ the parameter k approaches a definite limit k_1 when the frequency is high enough, and k_2 when the frequency is low enough.

Perhaps the best quantity to compare with experiment is the gain in signal strength with height above the earth in regions beyond the visual range. This gain of signal intensity with height has been measured by many observers in America, using either aeroplanes or autogyros. Examples of the results are given in Figs. 36, 37, and 38, which show that the calculated gains agree with the theoretical gains within a few decibels over quite a considerable range of height. The gains are plotted as a function of $h\lambda^{\frac{2}{3}}$, since the theory shows that they should be a function of this and this only. Thus it is again possible to check the theory without invoking the help of any arbitrarily-estimated earth constants. Although in the main agreement of observation and theory is very fair, individual cases of wide divergence have been recorded. Englund, Crawford, and Mumford have given an example where there was practically no gain with height well beyond the visual range. Again, they have found occasions where the field intensity just beyond the visual range has varied by as much as 20 db from one day to another. Such effects are no doubt due to refraction, which may on occasion produce profound variations, but if the present author's reading of the average results is correct such occasions are rather the exception than the rule. An estimate of the effect of atmospheric refraction can be obtained by comparing the observed results with the calculated ones.

THE ELECTRIC SUPPLY SYSTEM IN BERLIN

By M. W. HUMPHREY DAVIES, B.Sc., Graduate.

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SUMMARY

After a brief description of Berlin and its chief electric supply company, the Berliner Kraft und Licht (Bewag) A.G., the existing distribution system in Berlin is described in detail. Special reference is made to the introduction of low-voltage grids and to experiments in feeding them direct from 30-kV cables, the protective systems employed being also discussed. The paper concludes with a reference to the work done by the company's research departments.

CONTENTS

Terminology.
(1) Introduction.
(2) Berlin and the " Bewag."
(3) The Three-Voltage Group System.
(4) The Two-Voltage System.
(5) Tendencies in Urban and Suburban Development.
(6) Protection.
(7) Conclusion.
(8) Bibliography.

TERMINOLOGY

The following terms are used throughout the paper:—

" Distributing stations " are 30/6-kV substations with attendants, supplied from the 30-kV grid and feeding the 6-kV substations.

" Suburban distributing stations " are 30/6-kV substations of simplified design, usually unattended, which have been recently introduced for suburban areas.

" 6-kV substations " are 6-kV switch-houses fed from the local distributing station and supplying neighbouring transformer stations through ring mains.

" Transformer stations " contain from one to three transformers (6/·38-kV in the Three-Voltage System, or 30/·38-kV in the Two-Voltage System) feeding the low-voltage network.

" Suburban areas " are areas in which the load density is less than 2 800 kW per square mile.

(1) INTRODUCTION

A critical comparison of electrical development in different countries is rendered difficult by contrasts in social, economic, and even climatic conditions in the countries under review. In the electric supply industry these differences have far-reaching effects on the nature of the load which can be developed, and also on the design of plant and the layout of distribution systems. In Great Britain a considerable part of the electrical energy sold for domestic purposes is used for heating; but in many parts of the Continent, because of the extensive use of steam-heating, the development of an electrical heating load becomes very difficult. This applies in particular to Berlin. As the temperature there is below zero during a great part of the winter, most of the people live in flats and houses that are equipped with steam central-heating. In order to obtain a reasonable diversity factor for the domestic load, it is therefore necessary to pay particular attention to the sale of electric cookers and water-heaters.

In a similar way, economic and climatic conditions have their effect on the design of plant. The engineer visiting Germany is impressed by the absence of oil-filled ironclad switchgear, by the preference for open busbars, and by the rapid development of the expansion switch.

These national differences in electrical equipment are seemingly inevitable, and are not always easily explained. But the underlying problem facing the supply engineer—the provision of a constant and reliable supply of electricity as economically as possible—is universal. Countries often have their own methods of approaching it; and, though local conditions will affect the details of the solution, the general principles adopted may open up fresh lines of thought to those facing very different local requirements.

Last year, through the kindness of Dr. Adolph, one of the managing directors, the author was privileged to spend a few months in Berlin as the guest of the Berliner Kraft- und Licht- A.G., that is, the Berlin Power and Light (Bewag) Co., the " Bewag " as it is called in Germany. It is the purpose of this paper to describe how in the year 1924 the company attempted to solve the distribution problem for a large industrial city by treating it as a single unit, and how, in 1929 and subsequent years, these plans were modified in the light of experience.

It is not possible in a single paper to deal adequately with the whole of the Bewag organization, or to attempt to analyse the whole chain of cause and effect that gave rise to the present system and made the company one of the best-known in Germany. But, in order to understand the significance of the latest developments, it is desirable to say a little about Berlin and the growth of its supply system during the last decade. Other points of interest will be dealt with briefly, and the author would like to refer here to the Bibliography at the end of the paper. Most of the articles referred to were written by engineers of the Berlin Company, and have been of material assistance to the author.

(2) BERLIN AND THE " BEWAG "

Berlin—the centre of many German industries, including the electrical manufacturing industry—is a rapidly growing city. At the time of the Great War, Berlin itself was still comparatively small but was surrounded by a number of satellite towns, each possessing its own electric supply system. In 1920 these towns were combined to form Greater Berlin, which to-day is one of the largest cities in the world—more than half the size of Greater London, and with half the population of the latter.

Berlin now covers an area of some 360 square miles and has a population of just over 4 millions.* The average density of population is almost the same as that of Greater London; but the greater part of the population lives in flats, with the result that only 28 per cent of the total area is fully developed. This central district is bordered by lakes and forests covering a further 27 per cent, the remaining 45 per cent being mainly undeveloped country and small holdings. As a result of this concentration, the actual density of population in central Berlin is very high indeed. A park divides the city into two parts—old Berlin and Charlottenburg—and each of these forms a separate load centre, the maximum load density being about 56 000 kW per square mile.

Until 1929, the load was developing at the rate of 50 000 kW per annum; but the economic crisis was felt very severely in Germany and the load fell off considerably, though in this respect the Bewag fared no worse than most of the other German supply companies.

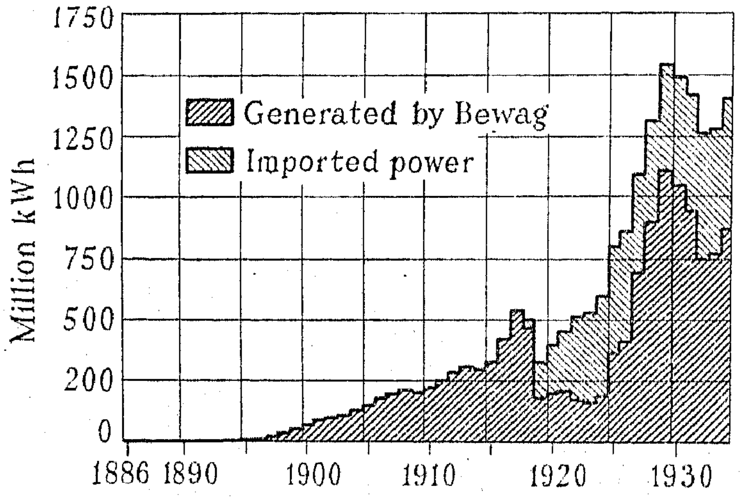

Fig. 1.—Development of Bewag load, 1884–1934.

During the last few years the load has gradually recovered, the average annual increase being just under 10 per cent. In 1934 the company sold 1 188 million units, with a peak load of 439 000 kW. The total consumption in Berlin (see Fig. 1) was 1 450·8 million units, that is 345·8 units per head of population, which compares favourably with other Continental cities.

The Bewag system load-factor was 36·2 per cent.† Noticeable features of the load curve (see Fig. 2) are the smallness of the midday valley and the size of the morning peak. These features are chiefly due to the heavy traction load connected to the system.

The bulk of the power is supplied from two large central stations, namely Klingenberg, east of the city, and Kraftwerk West, to the west. One of these stations maintains the frequency, using automatic relays for the purpose. A large part of the power for the base load is imported over 100-kV lines, which terminate in substations to the north and south-east. These lines bring power from Trattendorf and Zschornewitz, two large stations on the lignite field in Central Germany. These stations are relics of the Great War and have been extended from time to time. A list of the stations is given in Table 1.

In addition to the two chief stations in Berlin, there are a number of smaller and older stations which are kept in commission as reserves, but the only one of importance is the station at Charlottenburg, which was reconditioned in 1929. In 1926 this station, which is near the centre of the load, was equipped with pass-out turbines connected to a public heating system, and an experimental Ruths steam accumulator was afterwards installed. In 1929 the capacity of the steam accumulators was increased, and they can now deliver 73 000 kWh per charge at a maximum rate of 50 000 kVA.

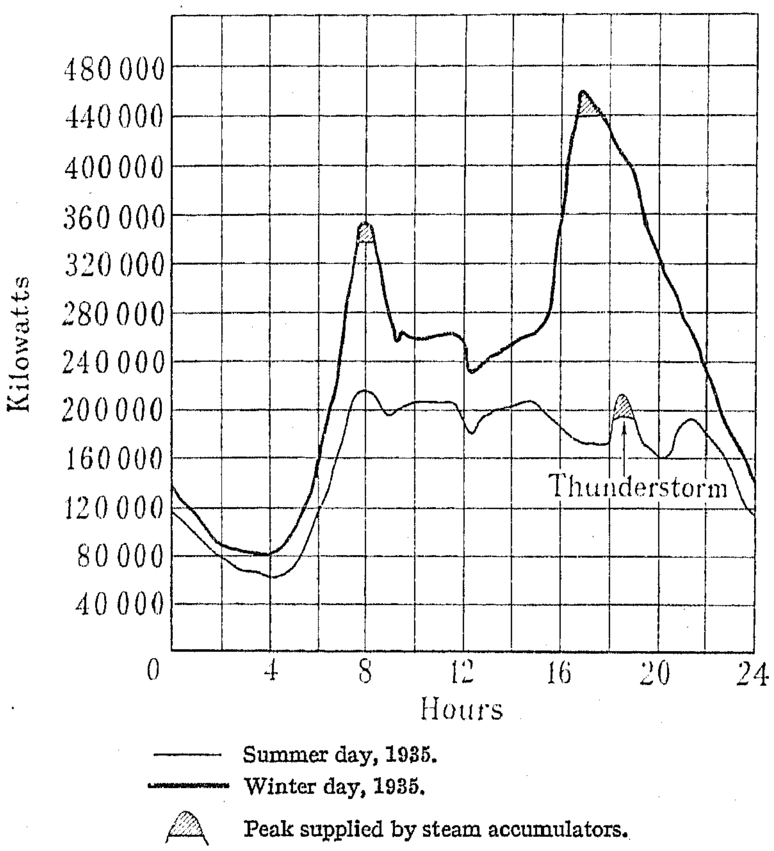

Fig. 2.—Typical load curves showing the use of the Ruths accumulators and also a lighting peak due to a thunderstorm.

For local-government purposes Berlin is divided into 20 districts, and 16 of these are now supplied with electricity by the Bewag. This unification was not a sudden achievement, but was the result of many years of careful planning. The movement started with the pooling of generating resources; then came the introduction of common tariffs. Financial mergers only took place when opportunities occurred. The company is controlled by two managing directors. One of these (see Fig. 3) is a commercial expert and controls the departments which are chiefly commercial; the other is a technical expert and directs the more technical departments. In most of the larger departments the principle of centralized control and decentralized area management has been followed for some years with very satisfactory results. One of the great advantages of this method lies in the economies achieved through inter-area

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* 4 024 286 at last census.

† This figure is based on the total number of units generated and the system peak-load.

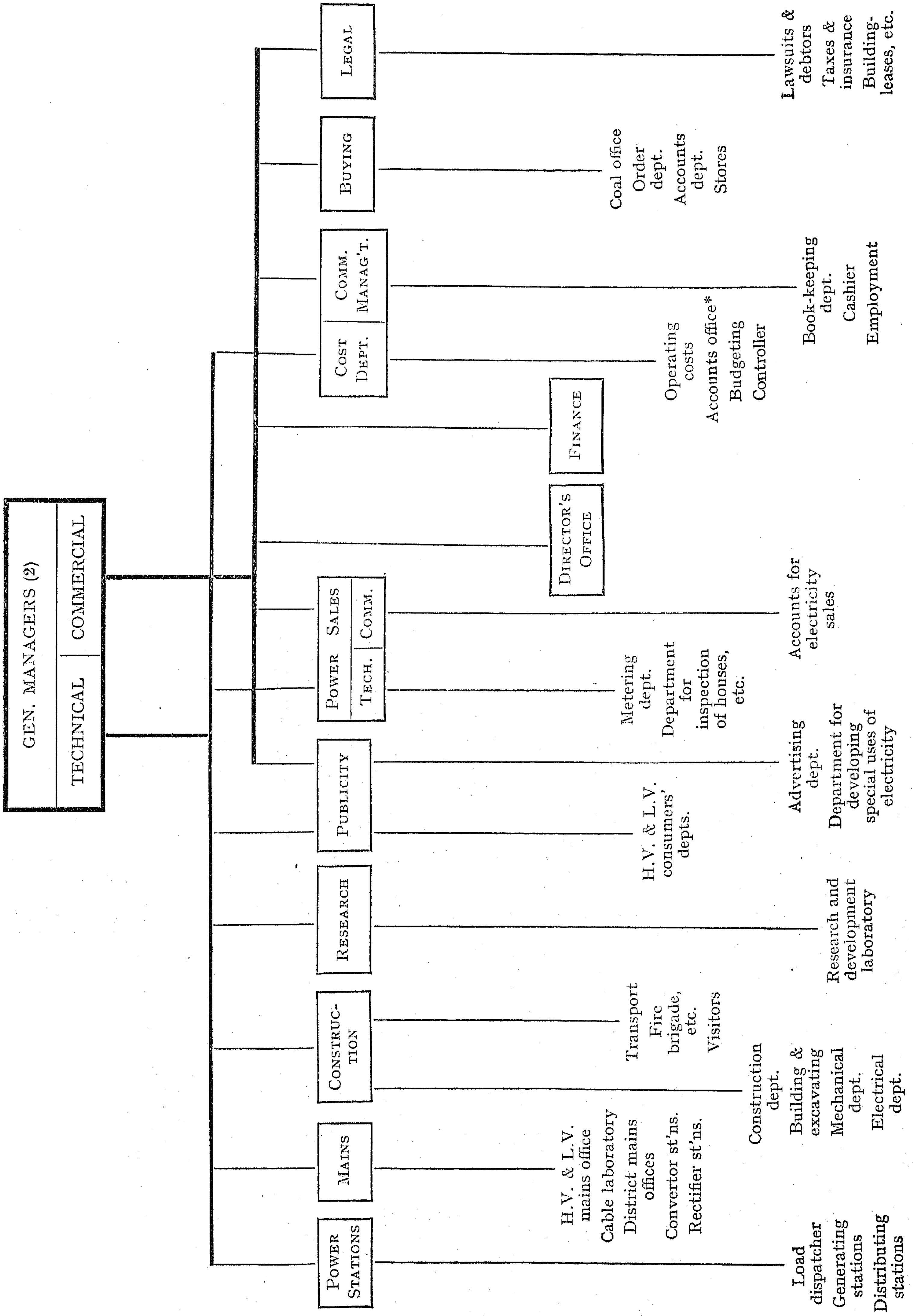


Fig. 3.—Organization of the Bewag, showing the main and subordinate departments.

* One of these is allotted to each department to keep the accounts.

competition and in the limitation of the district offices to a reasonable size.

Table 1

GENERATING STATIONS IN BERLIN

Date of construction	Name of station	Duty	Installed capacity kW
1926	Klingenberg ..	.. Base load	270 000
1930–32	Kraftwerk West	.. Day load	224 000
1929	Charlottenburg	.. Peak load*	50 000
Rebuilt 1925–6	Charlottenburg	.. Base load	54 000
—	Moabit.. ..	.. Winter peak load	77 750
—	Rummelsburg†	.. Winter peak load	69 200
—	Spandau ..	.. Local load	49 400
1910	Steglitz, etc. ..	.. Local load	6 600
	Total Bewag capacity		800 950

Other Sources.

	Name of station	Duty	Installed capacity kW
	Elektrowerke lines from Zschornewitz and Trattendorf	.. Base load	130 000
	Märkische E.W.	.. Local load	12 400
	Total available kW		943 350

* Accumulator available for 3 hours.
† The Rummelsburg station, which is an old one, has now been shut down but could be brought back into service in an emergency.

(3) THE THREE-VOLTAGE GROUP SYSTEM

The early development of the Bewag system resembled that in any other large town. At the beginning of 1924 three stations, all under 100 000-kW capacity, were supplying the load through radial 6-kV feeders. The system was divided into two sections, which since 1918 had been running in synchronism. The inter-

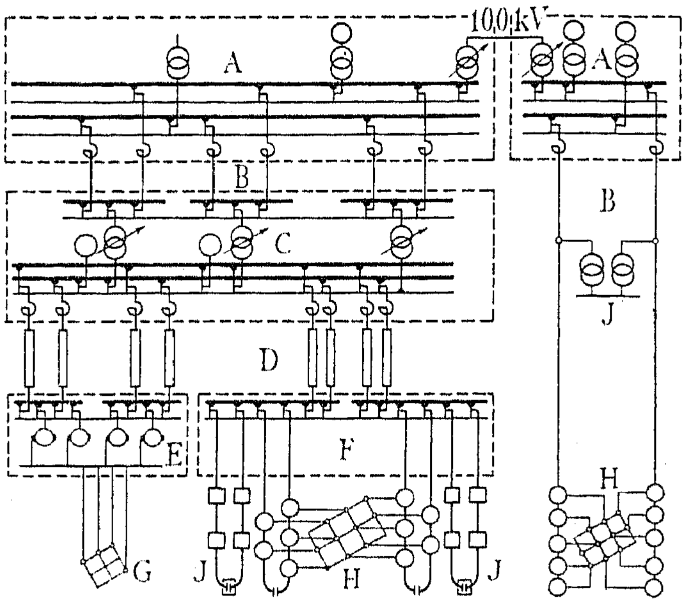


Fig. 4.—Principles of the Two-Voltage and Three-Voltage Systems.

A. Generating stations.
B. The 30-kV grid.
C. A distributing station.
D. The corresponding 6-kV radial network.
E. Convertor stations.
F. The 6-kV substations.
G. Low-voltage d.c. network.
H. Low-voltage a.c. network.
J. Bulk consumer at 6 kV.

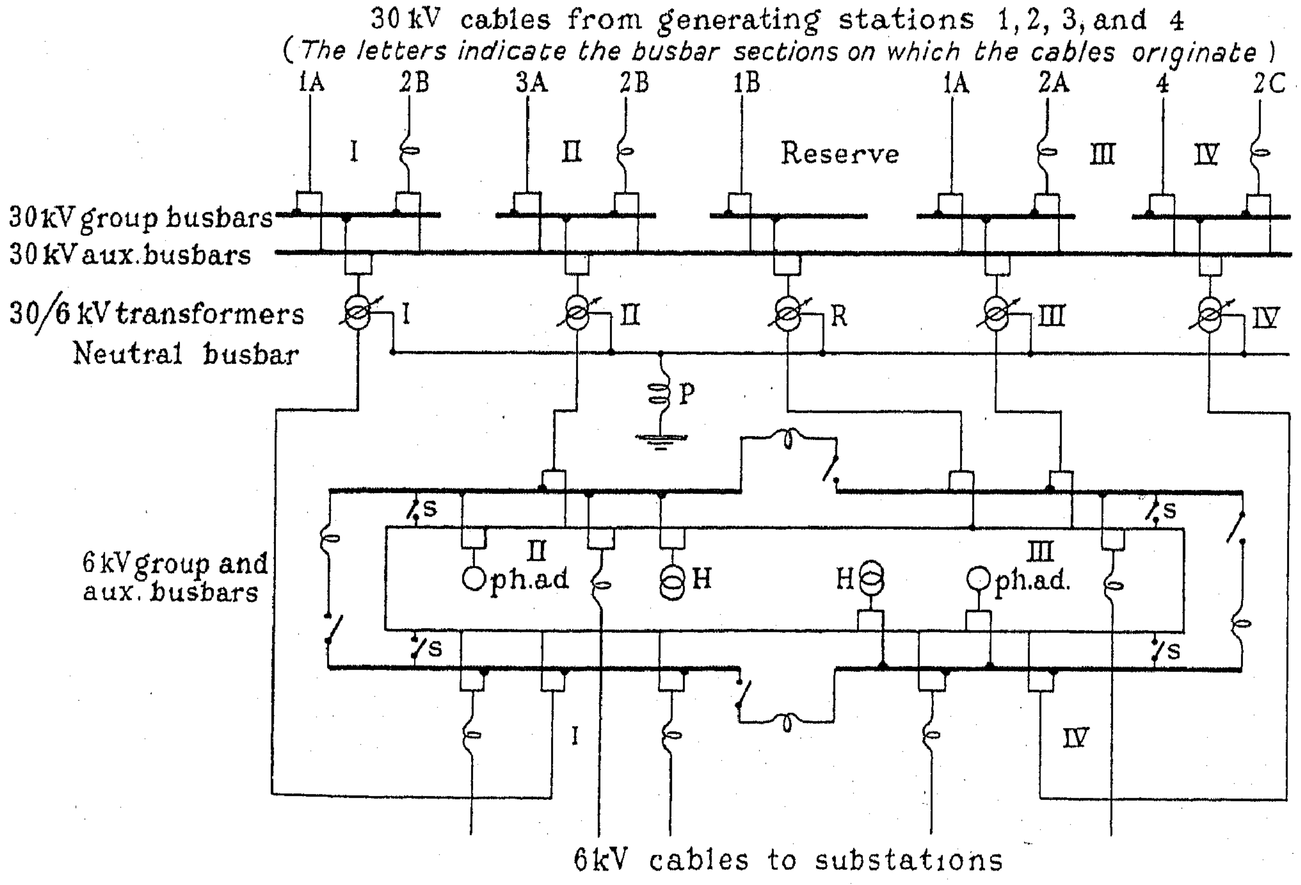

30 kV cables from generating stations 1, 2, 3, and 4
(The letters indicate the busbar sections on which the cables originate)
1A
2B
3A
2B
1B
1A
2A
4
2C
I
II
Reserve
III
IV
30 kV group busbars
30 kV aux. busbars
30/6 kV transformers
Neutral busbar
I
II
R
III
IV
P
S
S
6 kV group and aux. busbars
II
ph.ad
H
H
III
ph.ad.
S
S
I
IV
6 kV cables to substations

Fig. 5.—Schematic diagrams of distributing-station connections.

P.	Petersen coil.
R.	Reserve transformer.
H.	House transformer.
ph. ad.	Phase advancer.
S.	Coupling switches for connecting auxiliary busbars to group busbars.

⊥ Switch normally open.

Switches which are normally closed are indicated by a black dot on the busbar.

NOTE.—The layout of the 6-kV substations is similar to that of the 6-kV switch-house in the distributing stations. The coupling switches are closed automatically if the normal supply fails.

connection was made over the two 100-kV overhead lines from the stations on the lignite field. Between 1924 and 1930 the two large central stations were built. When the first station was being planned in 1924 it was proposed to connect it with the 100-kV substations, which lay approximately north and south, by a double 30-kV ring. But about that time Dr. Rühle of the Bewag visited America, and on his return the company decided on a 30-kV grid from which the low-voltage system should be fed through radial 6-kV feeders.

This system became known as the "Three-Voltage Group System" because of the three voltages used, namely 30 kV, 6 kV, and 380/220 volts, and because the networks were divided into groups and so arranged as to make the effect of the failure of any single unit, such as a cable, very slight. For this purpose Berlin was divided into a number of sections; there are now 24 of these sections, with peak loads varying from 20 000 to 50 000 kVA in the central area. All the substations in each section are supplied from a single distributing station (30-kV substation) connected to the 30-kV grid and situated near the centre of the section. Fig. 4 shows diagrammatically the principles of the scheme. At the top are parts of the busbars of two independent generating stations, the power in each busbar section being limited to 100 000 kW. The two stations are interconnected by a number of 30-kV cables of 0·15 sq. in. cross-section. Each of these cables is looped-in to a 12 500-kVA transformer in one of the distributing stations. The cables are each rated to transmit 8 000 kVA continuously, which allows a considerable margin for interchange of power between stations.

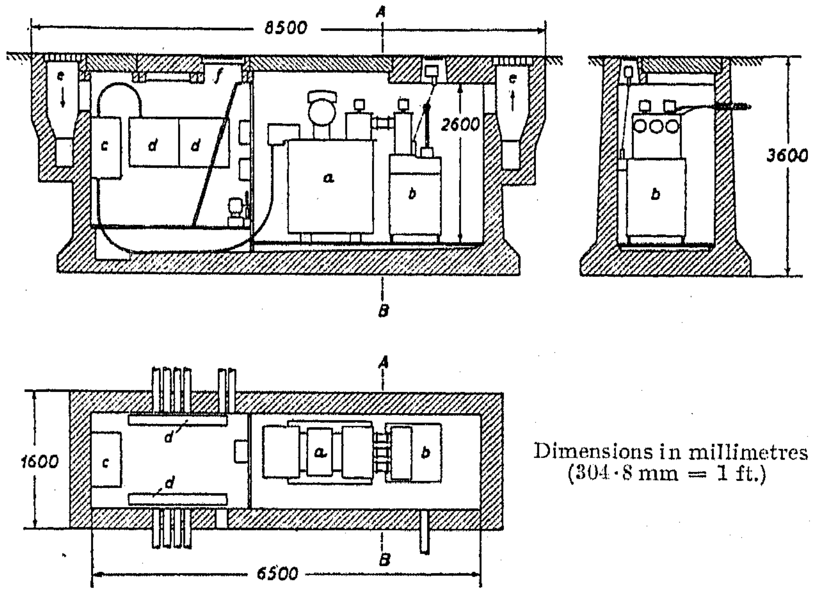


Fig. 6.—Transformer station (30/·22 kV) for the Two-Voltage System, constructed beneath the roadway.

a. 250-kVA transformer, 30/·22 kV with off-load tap-changing.
b. 30-kV isolating switch (oil-immersed).
c. Low-voltage automatic switch.
d. Low-voltage cable terminals.
e. Ventilators.
f. Entrance.

The 30-kV/6-kV step-down transformers are not interconnected at all on the high-voltage side and only through reactors on the low-voltage bars; each has its own pair of supply cables and its own section of busbars. In some of the larger stations a reserve transformer is kept on the auxiliary busbars ready for instant use. The 6-kV substations and the convertor stations for the underground railway and the d.c. network—there is still an extensive d.c. network in the central part of Berlin—are supplied through 6-kV radial feeders, each consisting of a pair of 0·11-sq. in. cables in parallel, each rated at about 3 600 kVA. The busbars in these substations are divided into three or four sections, each supplied from two independent sections of the distributing-station busbars. A spare cable is connected to the auxiliary busbars and is brought into service automatically when a cable fails (see Fig. 5).

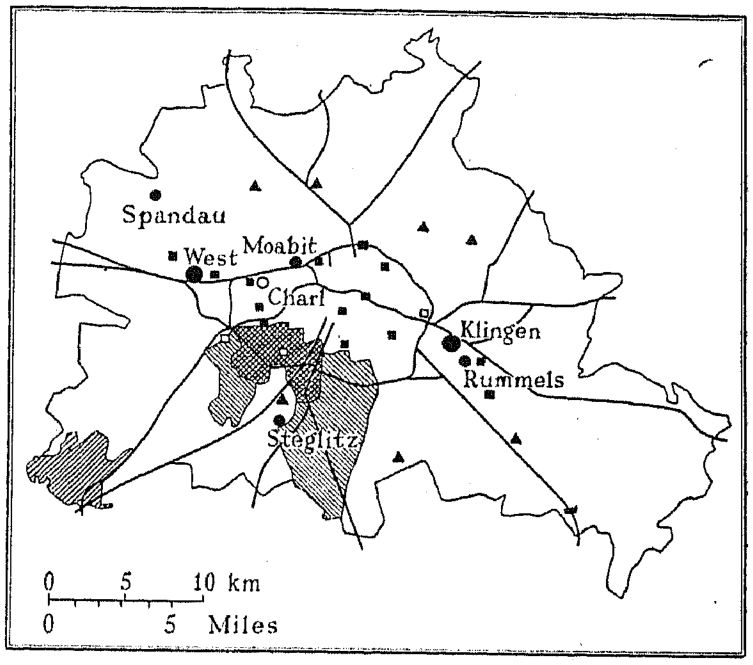


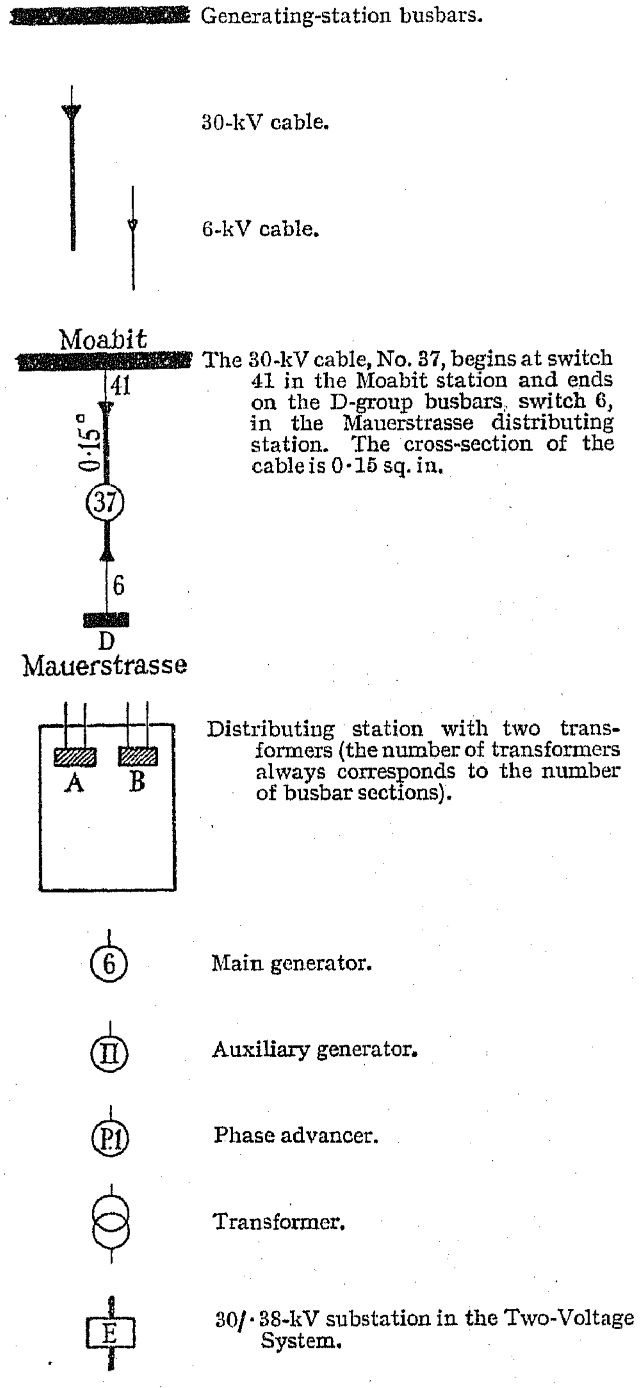
Fig. 7.—Plan of Berlin showing generating stations and distributing stations.

● Generating stations over 200 000 kW.
• Generating stations under 100 000 kW.
○ Generating stations with Ruths accumulators.
■ Distributing stations (Bewag).
□ Distributing stations (other companies).
▲ Suburban distributing stations (unattended).
☐ Area supplied by Bewag.
▨ Area supplied by other companies.
▩ Area supplied by other companies, but interconnected with Bewag system.
—— Railway lines.

The low-voltage networks are supplied from small transformer stations containing two or more transformers rated at 250 or 160 kVA according to requirements. These stations are usually housed in the cellars of houses and factories; transformer kiosks and special buildings are rarely used. The transformers are supplied through 6-kV rings from the substations, the cables being rated to carry 2 000 kVA. The ring is kept open at the centre and is loaded to 1 000 kVA on each leg. In the event of a fault in a cable section or station, the faulty section is cleared and the remaining sections are fed through the ring. Bulk consumers are supplied from the 6-kV rings, but special feeders are allocated to hospitals and other essential services. Four-core (three 0·15 sq. in. and one 0·07 sq. in.) cables insulated for 1 000 volts are used for the 380/220-volt system.

(4) THE TWO-VOLTAGE SYSTEM

The Three-Voltage System was completed in 1927, and since that time there has been no serious interruption to the supply in Berlin. In 1929, a simpler and more economical system was devised by the Electrical Research Department. This system, which is only suitable for areas of comparatively high load-density, was called the "Two-Voltage System" because it was proposed to discard the costly distributing stations and to feed the low-voltage mains direct from 30-kV cables radiating from the power stations, the 6-kV system being retained only for bulk consumers.



Generating-station busbars.

30-kV cable.

6-kV cable.

The 30-kV cable, No. 37, begins at switch 41 in the Moabit station and ends on the D-group busbars, switch 6, in the Mauerstrasse distributing station. The cross-section of the cable is 0·15 sq. in.

Distributing station with two transformers (the number of transformers always corresponds to the number of busbar sections).

Main generator.

Auxiliary generator.

Phase advancer.

Transformer.

30/·38-kV substation in the Two-Voltage System.

Key to **Fig. 8.**

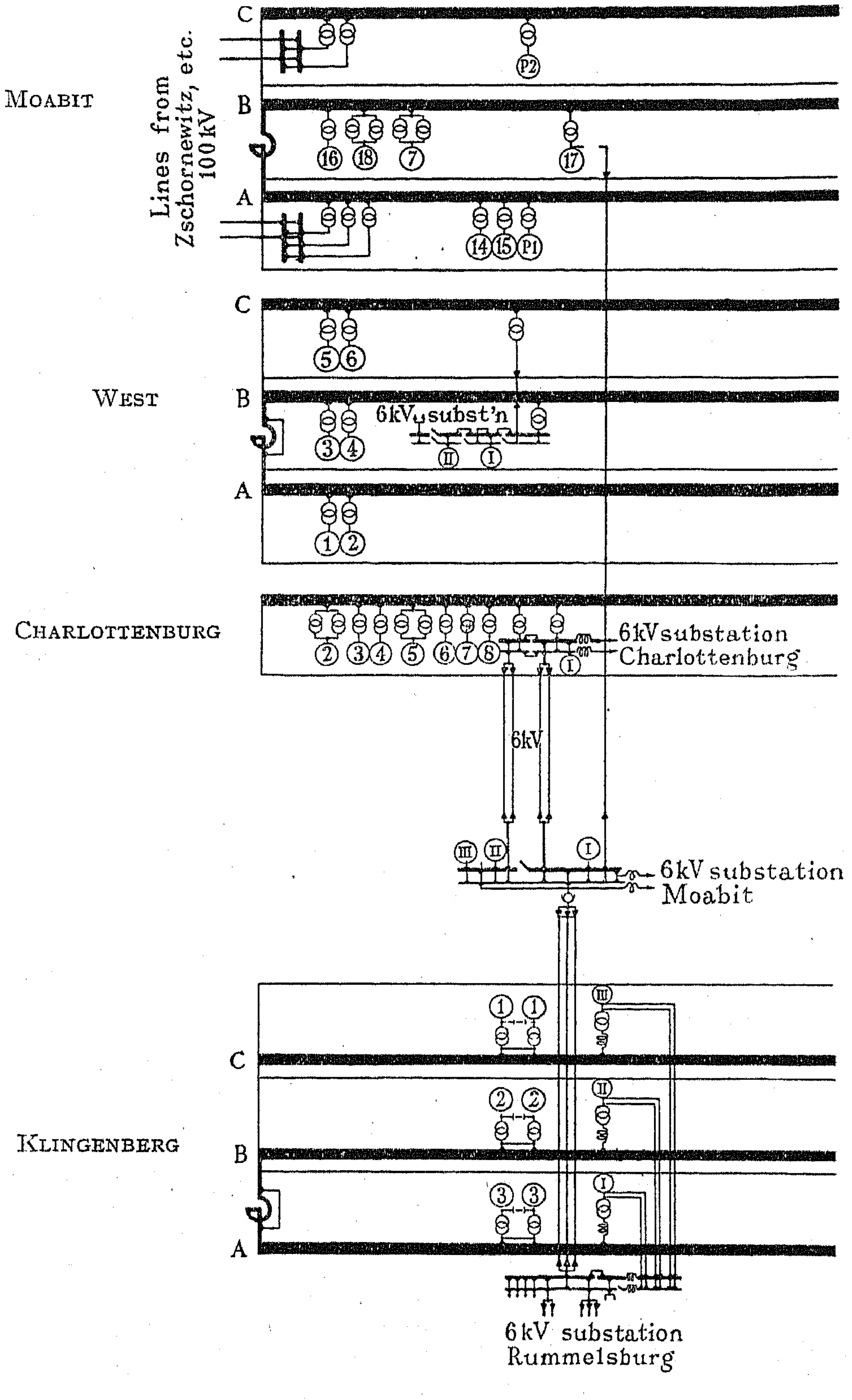


Fig. 8.—The Bewag 30-kV System.

This illustration shows a part of the system diagram used in the central control-room. The diagram is printed and circulated at intervals to all departments concerned with the network. In the diagram the thick horizontal lines represent the sections of the 30-kV busbars in the generating stations; the vertical lines are the 30-kV cables. They terminate in the distributing stations, which are represented by squares enclosing a number of busbar sections; each of these sections has a separate transformer. The 6-kV systems are shown on a separate diagram which is not reproduced here. The distribution of the generators is shown in the left-hand part of the diagram; it can be seen that sections A

To work this system satisfactorily, two conditions must be fulfilled. First, the low-voltage cables must be connected up in a series of grids, each grid being fed by a number of 30-kV cables. When this requirement is met, the failure of any 30-kV cable will hardly be noticeable. The second requirement is a reliable switch at the feeding points, which will prevent the network from feeding back into a faulty 30-kV cable.

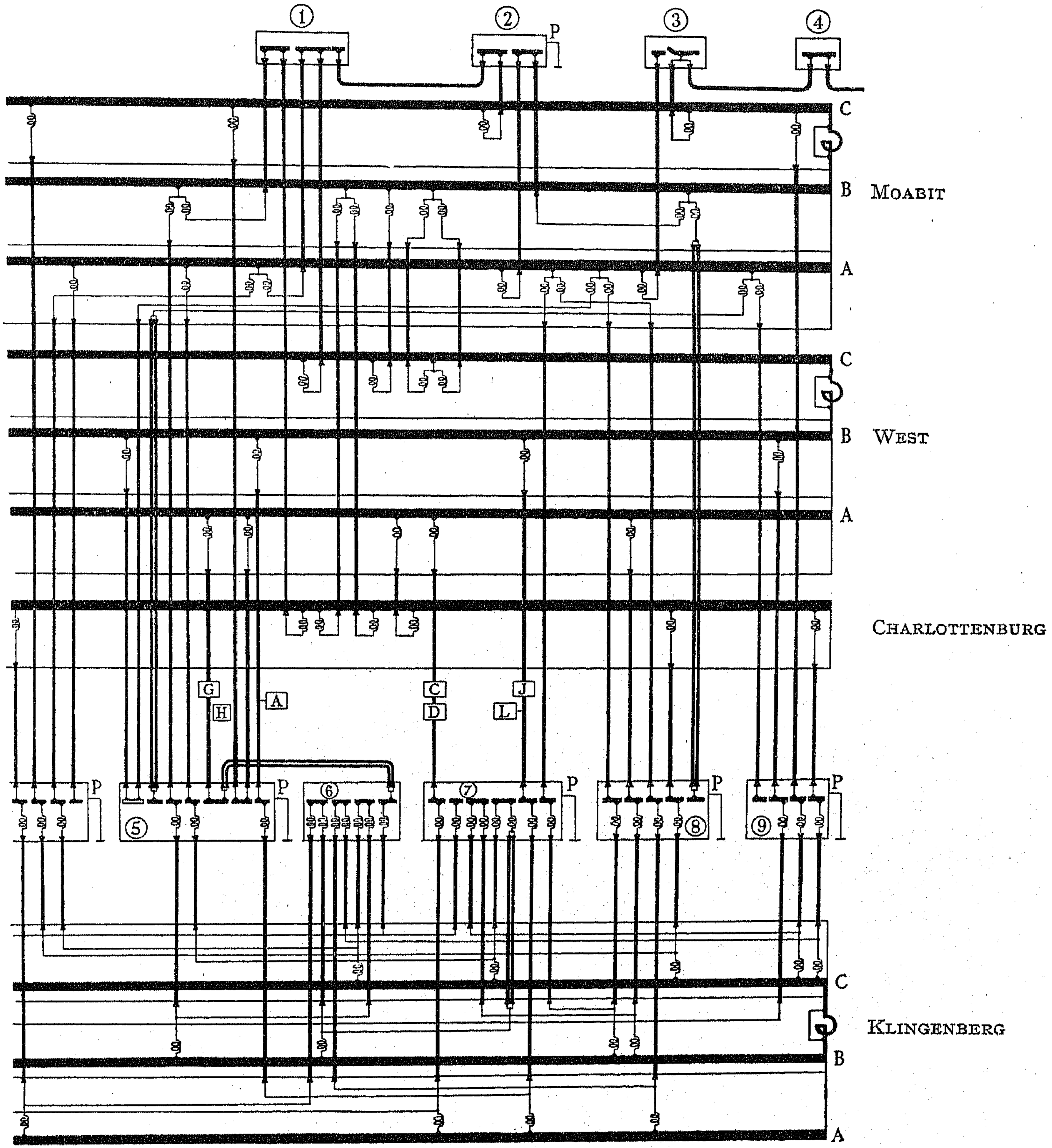


Fig. 8 (*continued*).

and C of the Moabit station are supplied mainly from the Trattendorf and Zschornewitz lines. Close to the generators a small 6-kV network can be seen; this is designed to safeguard the auxiliary supplies.

[Note.—The original diagram contains a great deal more information than is given here. The rating of each generator, phase advancer, and transformer, the reference numbers of transformers, cables, and switches, the dimensions of the cables, and the settings of the Petersen coils, are all clearly shown and a small plan at the bottom of the diagram shows the relative positions of the various stations. The points at which the network is to be opened in emergencies are indicated by coloured marks.]

A suitable switch was completed in 1930 and the first network was laid down. The unit consists of an ordinary air-break switch on the low-voltage side of the transformer, arranged to trip whenever the main circuit breaker supplying the 30-kV cable opens, and to close when the transformer secondary voltage rises to normal.

The most interesting installation is that in Charlottenburg, a busy centre of the city, where the new system has been used to strengthen the existing network. A single 220-volt grid is fed simultaneously from the existing 3-kV* substations and also from a number of new 30-kV/·22-kV transformer stations (see Fig. 6) supplied from the existing high-voltage grid. These stations are very compact and some of them are constructed beneath the road. This installation demonstrates the flexibility of the Two-Voltage System. Fig. 7 is a plan of Berlin, showing the location of the generating stations, distributing stations, etc.

The costs of the new system have been carefully investigated by the company. The extra cost of 30-kV cables and of the 30-kV/·38-kV transformers is offset by the elimination of the 30-kV distributing stations and the 6-kV cables. It appears that the capital cost of the Two-Voltage System is substantially less than that of the existing system, especially at high load-densities. The transmission losses are also considerably reduced. An essential feature of the Two-Voltage System is the low-voltage grid; an investigation showed that it was not economical to lay down such a grid unless the load density exceeded 2 800 kW per square mile.

(5) TENDENCIES IN URBAN AND SUBURBAN DEVELOPMENT

The success of the Two-Voltage System in the last few years has led to the preparation of plans for its extensive use in strengthening the existing system wherever it becomes inadequate. A steady increase in the load is to be expected in the next few years, and the operating engineers consider that the control of the network will become very difficult and that, should there be a complete shutdown, too much time would elapse before the supply could be restored. Great stress is laid on continuity of supply, and it is therefore proposed, as soon as the load reaches 1 million kW, to operate the network in sections with a peak load of 500 000 kW. To make this division possible, it is proposed to link the generating stations with a 100-kV ring and to divide the existing 30-kV grid into two sections. The most interesting feature of the changes proposed is the extensive part to be played by the Two-Voltage System.

In future, no new distributing stations will be built in the central part of the city. The 380-volt system is to be divided into a series of grids covering from 1 to 2 square miles. Plans have been prepared for supplying these 380-volt grids from 30-kV cables, on the principle of the Two-Voltage System. This will only be done when the existing 6-kV network becomes inadequate or, possibly, when the central district is changed over from direct current to alternating current. Each of these cables will cross a number of the low-voltage grids. A 0·15-sq. in. copper cable capable of transmitting 6 000 kVA, or an equivalent aluminium cable, has been chosen for this purpose. Such a cable has an economic length of about 10 miles and could supply fifteen 400-kVA transformer stations distributed along it, the first transformer being about 1 mile from the generating station. When the scheme has been completed, each section of the low-voltage grid will be supplied from at least six different cables, thus making the effect of the failure of one cable very slight.

In suburban areas, where the load density is less than 2 800 kW per square mile, the Two-Voltage System would not be economically practicable, so unattended substations with two transformers, fed from 30-kV radial feeders, will supply the low-voltage system through 6-kV cables. The size of these stations may vary from 1 000 to 16 000 kVA, the largest containing two 8 000-kVA transformers.

Although the low-voltage grids are an essential feature of the Two-Voltage System, they are equally applicable to any other system where a number of independent feed points are available. Their chief advantages are better voltage regulation and a reduction of the reserve transformer kVA required. The Two-Voltage System is still in the experimental stage in Berlin. The 11 existing 30-kV/·22-kV substations (see Fig. 8) are all looped-in to existing station interconnectors and do not represent more than 1 per cent of the Bewag load, but the construction of low-voltage grids has gone ahead rapidly and already over 20 per cent of the Bewag mains are connected in this way. The present policy is thus to divide the city into urban and suburban areas, urban areas being those in which the load exceeds 2 800 kW per square mile. Urban areas will be supplied from 380/220-volt grids, fed from existing 6-kV feeders strengthened where necessary by the 30-kV transformer stations in the Two-Voltage System. Suburban areas will be supplied from small unattended 30/6-kV substations.

Two recently-completed substations of this type are of considerable interest. The Bewag takes an active part in the development of new apparatus, and the Rummelsburg station is equipped with 6-kV compressed-air switches, while the one at Oberspree has water expansion-switches. Both these stations have attendants. They were put into service towards the end of 1934; so far they appear to have been satisfactory and it will be interesting to watch further developments.

At the Oberspree station, compressed air at 5 atmospheres is used instead of a solenoid for closing the circuit breakers and isolating switches, and the interlocks are pneumatic. This has meant great savings in battery costs and in the cost of pilot cables, only six small pilot wires being required for each switch and the relays requiring only 24 volts and a small current. These improvements have resulted in a saving of over 40 per cent in the equipment costs.

The control board is very compact and measures only 13 ft. by 7 ft. The switch controls are placed in the mimic diagram, and switch positions are indicated by a lamp in the centre of the control switch which flickers when the main switch does not tally with the control. The top half of the board controls the eleven 30-kV circuit breakers in the substation; the lower half controls the key sections of the 6-kV switch-house. There are thirty 6-kV cells; and most of the cable switches are controlled from the switch-house gangway. The whole layout of the control panel should encourage celerity and efficiency.

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* Part of Charlottenburg was originally supplied by another company through 3-kV feeders and 220-volt 3-conductor main .

(6) PROTECTION

The protection of the Three-Voltage System (see Fig. 10) is fairly straightforward. The short-circuit power is limited by means of reactors to about 300 000 kVA in the 30-kV mains, and to about 120 000 kVA in the 6-kV mains. A striking feature is the use of Petersen earthing reactances on a cable system. The earth-fault current in the 30-kV cables without Petersen coils is 3 000 amperes; in the sandy soil this is apt to cause dangerous potential gradients in the ground. For this reason, Petersen coils have been connected to the star-points of the primaries of the step-down transformers on the 30-kV system, to supply the total capacitative charging current of 3 000 amperes (see Fig. 9). In order to ensure correct discrimination by the protective gear the coils are distributed evenly over the network. They reduce the earth-fault current to 110 amperes, which, though sufficient to operate the protective gear, is no longer dangerous.

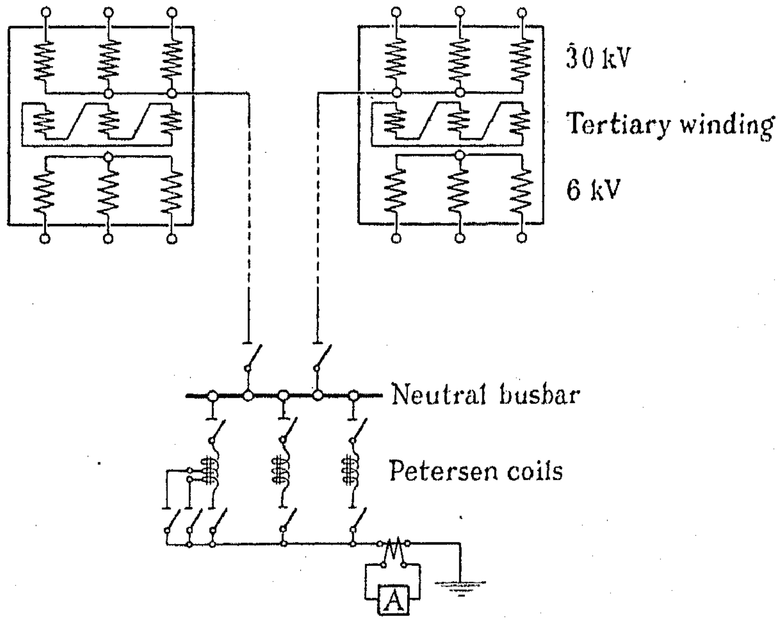


Fig. 9.—Connections for Petersen coils on step-down transformers.

The main 30-kV feeders are protected by impedance relays in three phases, with overload release. The station relays are set at 550 amperes, while those in the substations are given a lower setting (350 amperes) to ensure their operation to clear a fault on the station busbars. The 6-kV radial feeders are protected in a similar way, but in two phases only. The 6-kV ring mains have overload relays at each end. Earth-fault protection on the 30-kV system is provided by zero-phase watt relays, because zero-phase current relays are not selective when Petersen coils are used.

On the 30/6-kV distribution transformers (see Fig. 10), protection is provided by directional impedance relays in two phases; internal faults are cleared by differential-current and Buchholz relays; normally there is no special earth-fault protection, but in a few exceptional cases a zero-phase current relay is provided for faults to earth. The Bewag carried out considerable development work on the design of Buchholz relays, and since 1933 they have taken the place of differential watt relays on all transformers. The only protection on the small distribution transformers, which are rated below 1 000 kVA, now consists of temperature relays for protection against overload, and Buchholz relays for internal faults.

All Buchholz relays are carefully tested before installation. The relays on the larger transformers have two floats; one gives an alarm if gas collects in the vent pipe, and the other trips the circuit breaker if there is a rapid flow of oil in the pipe. The settings must not be too low or the transformer is apt to come out on a sudden increase in load. The action of the relays is very rapid and reliable; tests suggest that they should act faster than the older systems. Though it is too early to say how far they can be relied upon to clear faults on *large* transformers in service, the Bewag engineers show increasing confidence in them.

In the Three-Voltage System the 380-volt grids are fed from 400-kVA transformer units. The 6-kV supply enters the station through an oil circuit-breaker capable of breaking normal currents (see Fig. 11). The outgoing cable to the next station is teed-in over an isolating switch to the busbars; there is thus only one circuit breaker for each section of feeder. Cable faults are cleared by the circuit breakers in the 6-kV substations. The transformer is protected by Buchholz and temperature relays which trip the 6-kV circuit breaker; one of the special automatic switches similar to those used on the Two-Voltage System prevents the grid from feeding back into the transformer.

The short-circuit current going into the network is limited to keep the maximum fault current in the grid below 18 000 amperes. This is achieved by means of a differential reactor. The supply is brought to the mid-point of an air-core choke, half the load being connected to each end. The ampere-turns in each half oppose one another and, under normal conditions, are approximately equal. Thus the voltage-drop on normal loads is negligible; but, when a fault occurs on one leg, that half of the coil exerts its full choking effect. The distribution of load between the stations is usually satisfactory but can be regulated, if necessary, in a simple manner by placing packets of iron plates round the leads on the low-voltage side of the transformers. These increase the apparent reactance of the transformer and diminish its share of the load.

The use of Buchholz relays makes the protection of the Two-Voltage System (see Fig. 12) comparatively simple in principle, but it is complicated by the need for pilot cables to connect the relays in the transformer station to the circuit breaker in the generating station. For the Two-Voltage System simple overload protection is provided at the generating station. and the 30-kV/·38-kV transformers (400 kVA) have Buchholz and temperature relays; these trip the main circuit breaker, which trips and blocks " automatic switches " on the low-voltage side of the transformers. The " automatic switches " are simple air-break switches backed by fuses; these switches are an essential feature of the low-voltage grids. In the Three-Voltage System they are fitted with reverse-power relays arranged to trip if the reverse power exceeds full load, but with the Two-Voltage System these relays can be eliminated and the switch works in step with the main circuit breaker at the station end of the 30-kV feeder. The reclosing device consists of a voltage relay, which closes the switch when the trans-

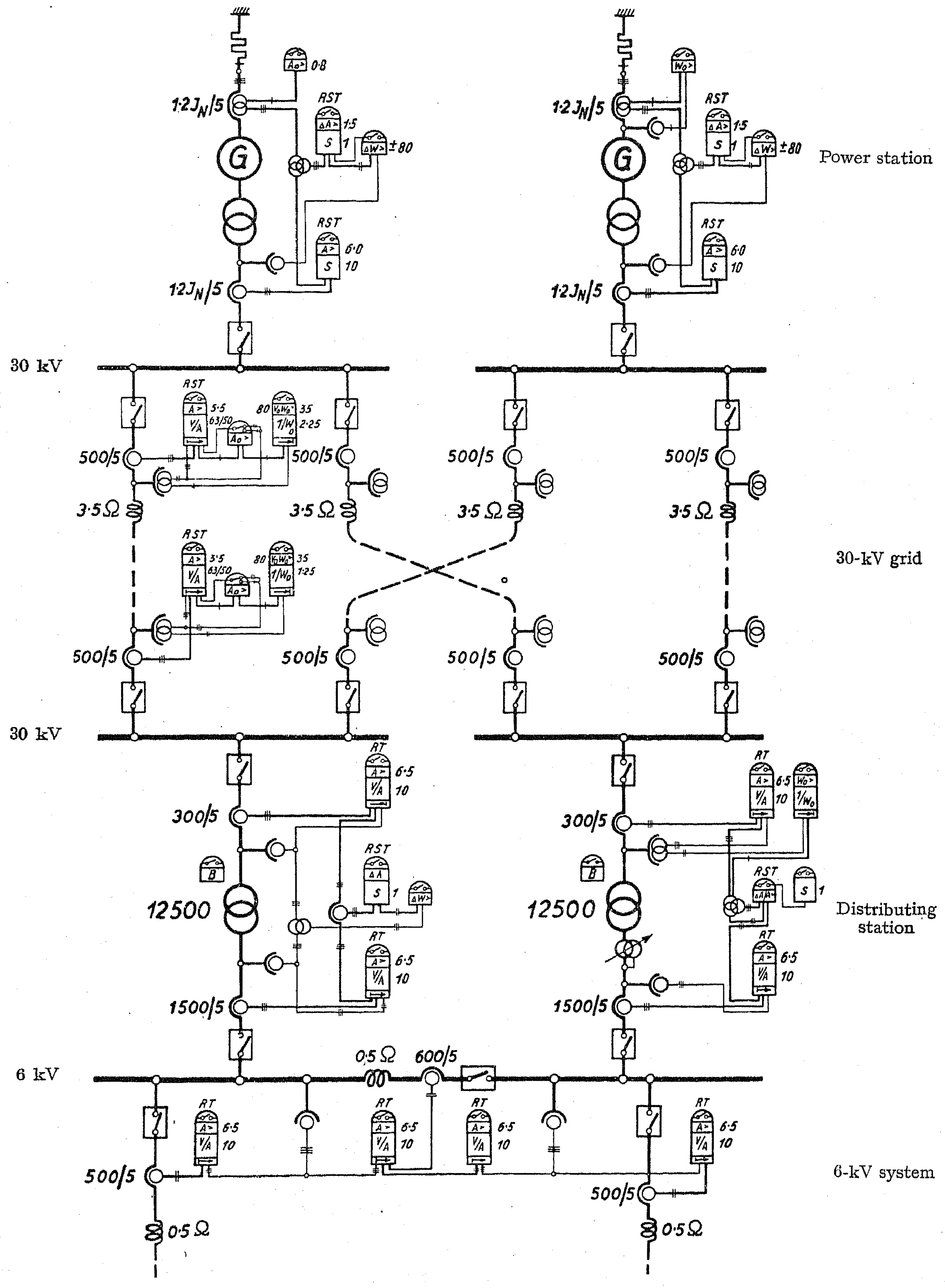
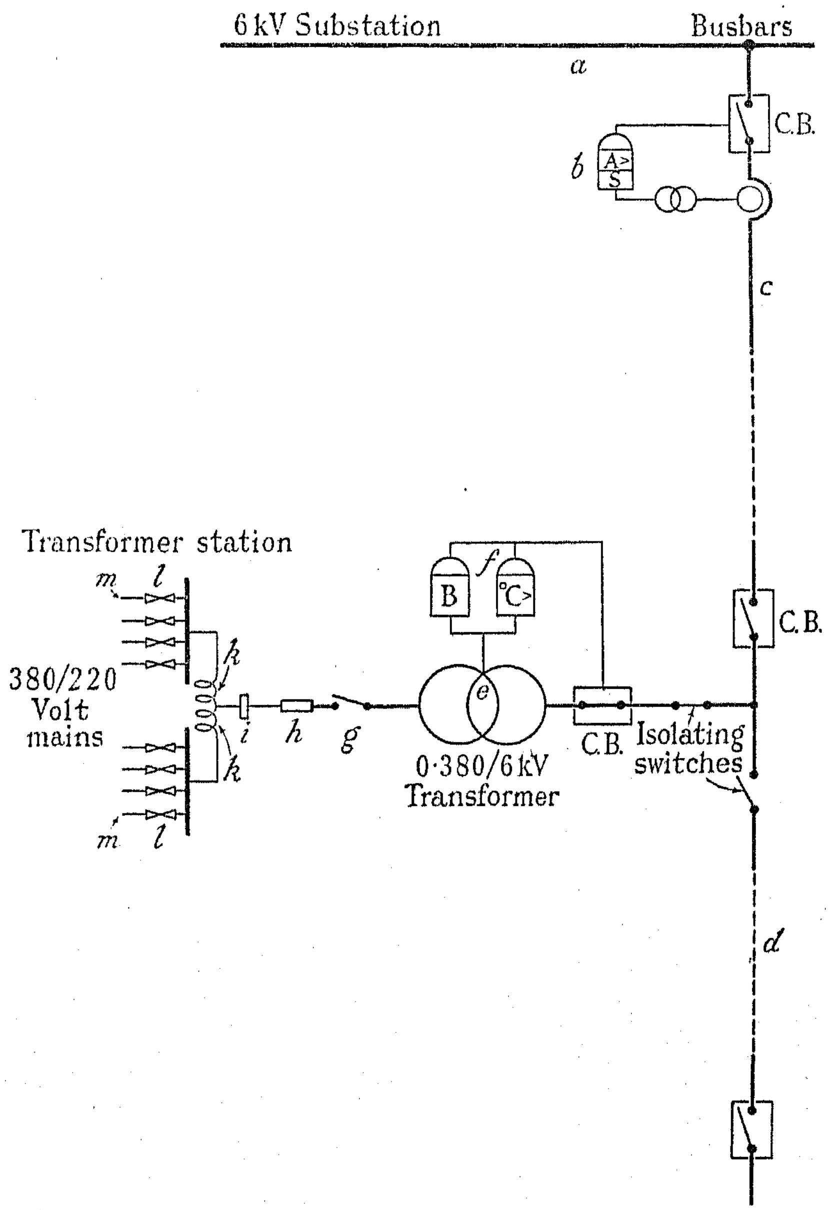


Fig. 10.—Protection for the Three-Voltage System.

[Note.—See key to Figs. 10, 11, and 12, on page 316.]

former secondary-voltage comes up to normal. The switch is closed by a small motor and is opened by springs; a blocking relay prevents a faulty switch from chattering. On the Two-Voltage System, four pilots are required to operate these switches, but the pilots are common to all the transformer stations on the cable.



a. Busbars in 6-kV substation.
b. Overcurrent relay; 10 amperes, 1·5 sec.
c. 6-kV ring main (3/·1 sq. in.) entering feed point.
d. Outgoing 6-kV cable to next feed point.
e. Transformer: 6 000/400 V ± 4 per cent, 160–320 kVA.
f. Temperature and Buchholz relays.
g. Automatic switch with reverse-power relay.
h. Main fuses.
i. Iron reactances for load adjustment, if necessary.
k. Balanced reactances to limit short-circuit current.
l. Cable fuses, 15 000 amperes in 0·12 sec.
m. Low-voltage cables (3/·15 + 0·07 sq. in.).

Fig. 11.—Protection for the 6-kV rings and 6/·38-kV transformer stations (Three-Voltage System).

[Note.—See key to Figs. 10, 11, and 12, on page 316.]

When the plans for the 380-volt grids were being laid down, the most difficult problem was the clearing of cable faults. In a grid system the short-circuit currents are much higher than in a radial system; although, in Berlin, the current is limited by chokes to 18 000 amperes, this is more than the ordinary cable fuse can clear. As the use of small circuit breakers in cable junction-boxes would have been too costly and no suitable fuses were available, experiments were made on a series of cables to see if these could be made to clear themselves. Grid systems without fuses were already working in America but at lower voltages.

The Berlin 380-V/220-V mains consist of 3-core armoured and belted cables (three 0·15 sq. in. and one 0·07 sq. in.) laid in sandy soil at a depth of from 2 ft. to 4 ft.; the cables are protected by clay covers moulded to fit the cable. Extensive tests showed that at 380 volts, if the fault current was greater than 500 amperes and less than 18 000 amperes, a small piece of cable would be burnt away and the arc would then be extinguished. With currents greater than 18 000 amperes, S.L. cable had to be employed. Eventually, an experimental network was laid down in which no fuses were used. The experiment was highly satisfactory; clearing times appeared to range from a few cycles to a few seconds.

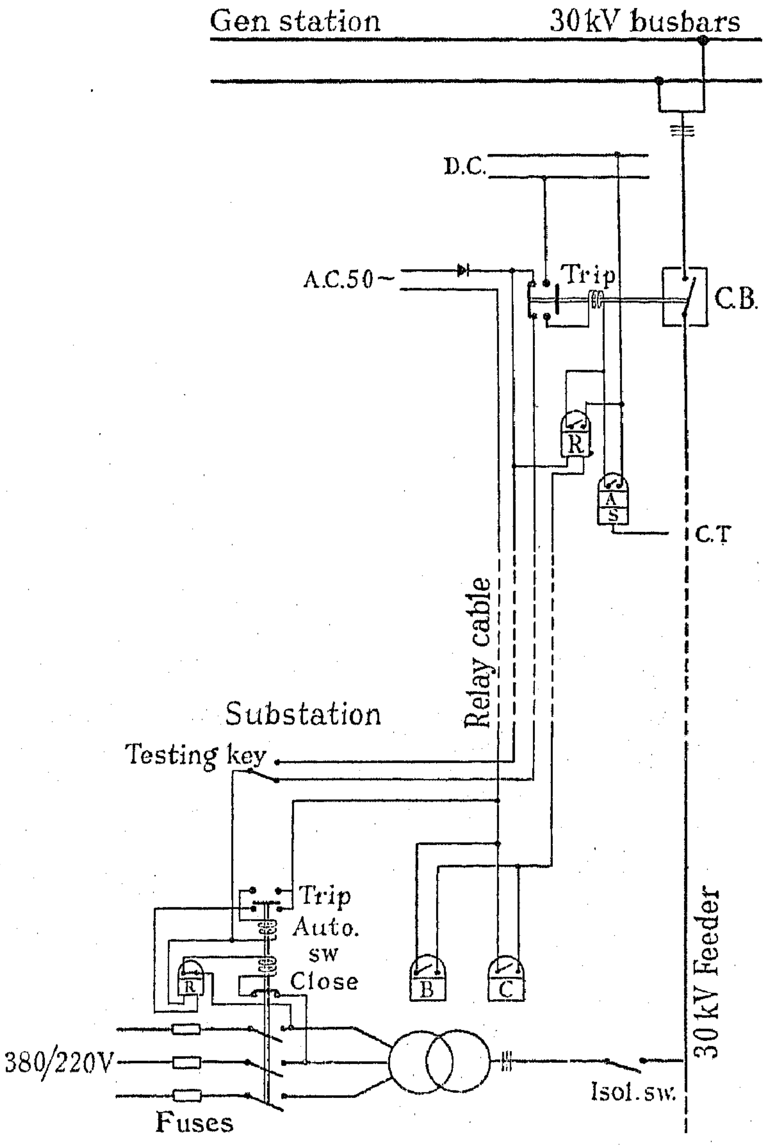


Fig. 12.—Protection for the Two-Voltage System.

[Note.—See key to Figs. 10, 11, and 12, on page 316.]

The only difficulty with this method of fault-clearing would appear to be that of knowing when a fault had occurred. All Bewag mains are tested once a year, and the Bewag engineers have hitherto found that all faults which do not immediately cause trouble can safely be left on until that time.

By 1930, a fuse had been developed which could break 25 000 amperes at 400 volts and 0·2 power factor. This fuse consists of a slotted metal cylinder in a tube packed with a suitable quenching powder; the total length is only 5 in. and the fuse can be mounted on an ordinary fuse-holder. The operating time is 0·12 sec. at 15 000 amperes, and 0·4 sec. at 4 500 amperes. This fuse is now widely used in the network, but, when the fault current is great, the cable frequently clears itself before the fuse has time to act. This would not happen if the system voltage were a little higher or if the cables were laid in ducts.

The methods of control and supervision were fully described by Dr. Schleicher in his paper before the Institution in 1934,* but it should perhaps be noted here that the only substations with attendants are the large 30-kV distributing stations and the large convertor stations. Three breakdown-gangs, normally engaged in miscellaneous fitting, are in constant attendance at different points in Berlin. Faults in the unattended stations are signalled automatically and are investigated by these gangs.

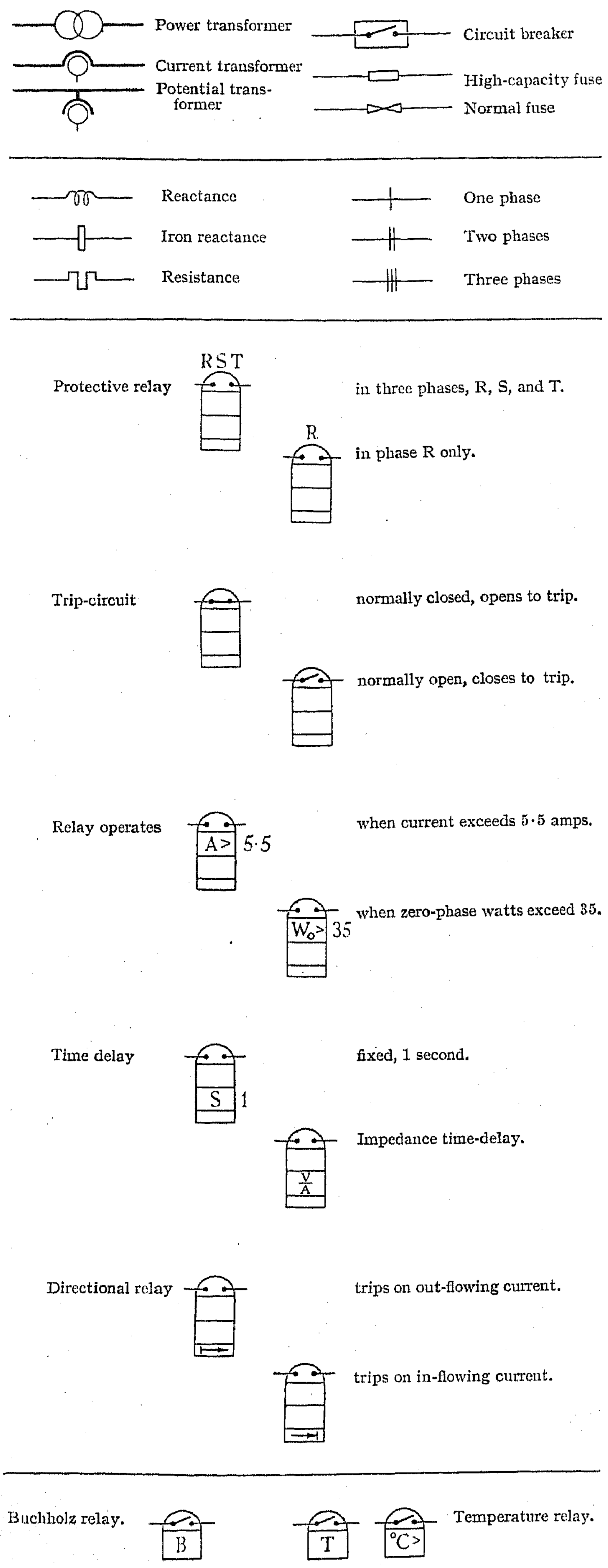
It was stated earlier in the paper that a part of the base load was supplied from a distance over 100-kV lines. The occasional tripping of these lines caused the operating staff considerable anxiety, and in 1929 the Ruths steam-accumulator units installed at Charlottenburg for assisting in dealing with the peak were adapted for use as an instantaneous reserve. One of the two 25 000-kW machines is kept constantly on the busbars and can be put on to full load in a few seconds. The main duty of these machines is to cover the morning and evening peaks, but they are also useful for dealing with unexpected demands at short notice. The batteries in the d.c. network are also used for this purpose and are then put on charge at night, thus increasing the night load on the system and helping considerably to maintain stability.

(7) CONCLUSION

The economies effected by standardization of equipment—especially substation equipment—and by centralization of management probably did much to help the Bewag to weather the serious economic crisis of 1929, and have enabled the company to continue its progressive policy without interruption.

One of the most valuable results of centralization was the setting-up of research laboratories and repair workshops for overhauling transformers, protective relays, and meters. These departments, with their first-hand knowledge of supply requirements and facilities for carrying out investigations under service conditions, work in close co-operation with manufacturing firms and have been able to devise numerous improvements in the design of plant. Another task carried out by these departments is the drawing-up of specifications. Very valuable work has been done by the company's cable-research department in studying the characteristics of cables, as a result of which the number of failures in over 600 miles of 30-kV cable has been brought very low. The figures are given in Table 2.

Some years ago the problem of peak loads was thoroughly investigated, and the results led to the construction of the Ruths accumulators; considerable research was done on the construction of low-voltage



Key to **Figs. 10, 11, and 12.**

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* *Journal I.E.E.*, 1934, vol. 75, p. 710.

grids, and a method of protecting rotary convertors against instability caused by momentary interruption of the a.c. supply has been successfully developed. More recently the company made an extensive investigation of telephone-interference phenomena, and is at present engaged on a study of circuit-breaker characteristics. The effect of mercury-arc rectifiers on the voltage wave has also been studied, and the company recommends that special precautions be taken to reduce the distortion at the rectifier transformers. As a result of these activities, the company's engineers have been able from time to time to give assistance to other companies in Germany and elsewhere, and the Bewag has become one of the country's leading electrical undertakings.

Table 2

30-kV Cable Failures

1929 ..	.. 13	1933 ..	.. 0
1930 ..	.. 10	1934 ..	.. 2
1931 ..	.. 3	1935 ..	.. 4*
1932 ..	.. 1		

* Of these, 2 were caused by excavators.

In conclusion, the author is glad to have had this opportunity of describing some recent electrical developments in Germany, believing that, if engineers in different countries can come to understand one another's peculiar problems and exchange ideas upon their solution, the progress of electrical engineering can be facilitated. He desires to express his thanks to Dr. Adolph of the Bewag for permission to present the paper, and to Dr. Wellman, chief of the company's construction department, for helpful criticism. He also wishes to thank the trustees of the Sir T. D. Owen Scholarship who enabled him to visit Berlin, and those engineers who helped to make his visit profitable, particularly Dr. Krohne and Dr. Schulze of the Research Department.

(8) BIBLIOGRAPHY

[Abbreviations: *E.T.Z.*, *Elektrotechnische Zeitschrift*; *E.W.*, *Elektrizitätswirtschaft*; *V.D.I.*, *Zeitschrift des Vereines deutscher Ingenieure*; *V.D.E.*, *Fachberichte des Vereines deutscher Elektrotechniker*; *Bewag*, Special publication of Bewag.]

The following list of publications written by engineers of the Bewag deals mainly with matters to which reference is made in the paper, and it is by no means exhaustive. A full list of publications up to 1934 will be found in the Appendix to Dr. Rehmer's paper (No. 1 below) and in "Fifty Years of Electricity Supply in Berlin" (No. 3 below):—

General.

(1) M. Rehmer: "The Growth and Management of the Bewag since 1924," *V.D.I.*, 1934, vol. 78, p. 539.

(2) J. Adolph: "The Jubilee of Berlin's Electricity Supply," *E.T.Z.*, 1934, vol. 55, p. 434.

(3) "Fifty Years of Electricity Supply in Berlin," *Bewag*, 1934.

(4) "The Sales Management Year-Books, 1925–34," *Bewag*.

Generating Stations.

(5) W. E. Wellmann: "West Station, Berlin," *Power*, 1932, vol. 76, p. 186.

(6) "Bewag Regulations for Laying-off and Putting into Service of Turbo-Generator Stations," *Bewag*, 1932.

Distribution.

(7) M. Rehmer and E. Krohne: "The Past, Present, and Future Development of the Bewag System," *E.W.*, 1930, vol. 29, pp. 1 and 36.

(8) H. Freiberger: "Self-protection of Low-Voltage Cable Grids by Burning-out," *ibid.*, 1930, vol. 29, p. 282.

(9) H. Freiberger: "Fuses for Low-Voltage Grids," *ibid.*, 1931, vol. 30, pp. 651 and 724.

(10) E. Krohne: "Service and Test Results with the New Low-Voltage Grids in Berlin," *E.T.Z.*, 1932, vol. 53, pp. 645, 720, and 731.

(11) E. Krohne: "D.C. or A.C. for Low-Voltage Systems?" *V.D.E.*, 1934, p. 25.

Protection.

(12) E. Neumann: "Tests with Petersen Coils on Cable Systems in Berlin," *E.T.Z.*, 1924, vol. 45, pp. 261, 294, and 1420.

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(16) Kaiser: "The Measurement of Dielectric Losses in Underground Cables," *E.W.*, 1930, vol. 29, p. 105.

(17) von Wiarda: "Modern Methods of Cable-Laying," *ibid.*, 1928, vol. 27, p. 595; and 1929, vol. 28, p. 162.

(18) Kaiser: "High-Voltage Cable Joints," *ibid.*, 1933, vol. 32, p. 404.

(19) K. Tonnemacher: "The Use of Aluminium for Cables, with special reference to jointing," *V.D.E.*, 1935, p. 57.

Switchgear.

(20) H. Freiberger: "Flashovers in Switchhouses on clearing Transformers," *V.D.E.*, 1935, p. 32.

(21) G. Hameister: "Experiments on the Frequency of the Restriking Voltage in High-Voltage Switchgear," *ibid.*, 1935, p. 42.

(22) F. Klostermann: "Switch-Houses for Large Cities; Distributing Stations at Rummelsburg and Oberspree, Berlin," *E.T.Z.*, 1935, vol. 56, p. 756.

[The discussion on this paper will be found on page 318.]

DISCUSSION BEFORE THE TRANSMISSION SECTION, 13TH MAY, 1936

Mr. C. W. Marshall: The great achievement of the Berlin electricity supply authorities in the last decade was the construction of the Klingenberg power station, with pulverized-fuel firing, which was built about 1926. What struck me most in connection with that station was the rapidity with which it was built: the whole of the construction, from the cutting of the first sod to the station coming into operation, took little over one year. The Kraftwerk West station, which followed about 1932, is less grandiose and was likewise constructed very quickly; it serves as a support to Klingenberg. What was very novel in European practice was the import of comparatively large proportions of the power and energy requirements of Berlin through overhead lines. Some of these go right into the fairly thickly housed sections of the town, while one 110-kV line goes up the centre of an important street. Another interesting point, to which the author draws attention, is the use of the steam accumulator for covering comparatively large peak loads of the order of 40 000 kW. This practice has been applied in a few cities, but, largely because of complications and high capital cost, it is commercially feasible only in special cases. The use of steam heating from Klingenberg for supplying very large hot-houses is a further noteworthy and somewhat uncommon feature.

Turning to the cable system, Berlin was the first city in which 33-kV cables were used. These were of the belted type and were first installed about 1911. It is interesting to find that even now there are no cables working at a higher voltage in Berlin. It would seem to me to be almost impracticable to raise the electrical consumption of Berlin to what is considered a reasonable figure per head of the population without superimposing a higher voltage.

The introduction of the low-voltage network system is in keeping with fairly common American practice. The German system differs from the American systems, however, in that it is more scientifically worked out; but in this connection it has to be remembered that while New York succeeded in maintaining almost perfect supply for many years, using grid networks of 220 volts, when trouble did occur the work of restoring supply was one of immense difficulty. I think it is largely for that reason that the network system, which is probably for 99 per cent of the time the best of all, does not come into more general use.

With regard to protection, is the Petersen coil used on any other large cable system besides that of Berlin? It must be a matter of great satisfaction to the engineers responsible for operation if they have succeeded in obtaining a thoroughly proved Petersen-coil system and so removed the difficulties associated with the heavy earth-fault currents inevitable with any other system.

The Berlin engineers have developed their protective system with great thoroughness. They have left nothing undone in the directions of good detailed finish, schemes for easy access to secondary wiring, and provision of convenient means for calibration of relays.

In comparison with, say, the London system, the Berlin system is remarkably simple. In London we have a very heterogeneous series of individually-operated networks of considerable magnitude, which have to be correlated principally through the London Power Co., the County of London Electric Supply Co., and the grid. It will be evident from a study of the connection diagrams of Berlin and London high-voltage systems that the former uses a much larger number of circuit breakers. The saving in capital cost in London by reduction both of switchgear and of space required for it has of course been attended with some loss of operating flexibility, but so far the British scheme has satisfied all requirements. It would be of interest to have the author's views on the relative merits of the two schemes.

Dr. P. F. Stritzl: The Berlin system is by far the largest underground cable system on which Petersen coils are used, but there are quite a number of smaller systems on which they are applied with equal success. There is a general belief that the main advantages of the Petersen coil are obtained when it is used on overhead networks, but, apart from the reason mentioned by the author, the reason which has induced the Bewag to apply Petersen coils is this: When a fault occurs on one phase of a cable, it tends, of course, to spread within a certain time to the other phases, and then constitutes a short-circuit. This time, with a solidly earthed neutral, would be extremely short, of the order of 1–2 sec., whereas with the Petersen coil in circuit the time is extended in the case of Berlin (where the magnetizing current is 3 000 amperes) to 1 hour or more. On a smaller system the time would, of course, be still longer. Every operating engineer will immediately appreciate the great value of having a margin of an hour or so in which to take the necessary measures.

Another way in which the Berlin system differs from others is in the application of low-tension grids. Some years ago the Berlin supply company were still doubtful how far they would go with this interconnection of low-tension mains, and whether it would eventually develop into one solid grid over almost the whole central area. I am very interested to see from the paper that they have now decided to subdivide the grid into 24 sections of about 2 square miles each. It would be interesting if the author could tell us something of what has led to the determination of this 2-square-mile area, and whether it is thought that this subdivision would eliminate such difficulties as have occurred in New York. Another point in connection with the solid low-tension grids is the economic side of their application. In Berlin the conversion to the solid grid system has been carried out very gradually, and it would be interesting to know whether a comparison was made of the expense which would have been involved if the same increase of load had been met by another system, with radial feeders.

The third and most striking difference between Berlin and any other similar system is the extensive application of distance relays or impedance relays on an underground cable network. It would be interesting to know whether these impedance relays—which are, as far as I know, of the high-speed type, and I think a great number of them are single-phase with change-over contacts, and not three relays in the three phases—are independent, or whether they are interconnected by pilot wires so that in the case of a fault near one end of the feeder they are both made to operate instantaneously.

Mr. E. Ambrose: On page 309 we are told that two generating stations are interconnected by a number of 30-kV cables, whereas Fig. 4 shows that there is a 100-kV connecting link. Again, in Fig. 5 a symbol is given to indicate a switch normally open and another symbol to indicate a switch normally closed, but it is not clear to which switches these symbols refer. Fig. 5 indicates a very liberal use of reactances. Is this feature due to the presence of the low-rupturing-capacity switches in the original 6-kV network, which would have been completely under-rated by the introduction of the 30-kV grid?

With regard to the development of the Three-Voltage System, considerable expense and trouble would of course be incurred in taking out the old 6-kV cables, and moreover in a densely populated area these cables could be used for bulk supplies. On further extensions into the urban areas there seems to be no justification for the use of the middle voltage of 6 kV. It should be possible to pass direct from the 30-kV to the 380/220-volt supply.

The author lays great stress on continuity of supply, and in this connection I would point out that, whilst I have nothing against interconnection, it often means placing a great deal of reliance on an ever-increasing and complicated system of relays, which have to function to isolate the faulty section.

The allocation of special mains to hospitals and other essential services is a very good feature, and in this connection I recall a special cable which was installed in the West End of London in order to give an emergency supply to theatres and newspaper offices. With regard to the low-voltage distributing network, there are far more possibilities of failure on this than on the higher-voltage system. This would seem to have been realized by the Berlin engineers when they introduced cables insulated for 1 000 volts on the 380/220-volt system.

The author mentions a high-rupturing-capacity fuse for the interconnection of the low-voltage grid; but is this going to solve the problem altogether? I ask this question because I have had some sad experience in connection with a low-voltage network which was connected solid, and when a fault did occur it took some time to put it right. Later the network was subdivided and fuses were introduced, but again when trouble occurred it took a considerable time to find out which was the fuse responsible for the trouble.

Mr. W. Fennell: The omission of the intermediate link of 6 kV between the 33-kV and the 0·4-kV system is, of course, not an entirely new proposal. It has also been adopted in this country to a certain extent.

With regard to the low-voltage grid, I have heard of several cases in this country where it has been tried out within the last 20 years, and in almost every case difficulties have arisen.

I am interested to see that a new fuse has been produced to deal with the rather heavy conditions on the Berlin system. Similar fuses, very reliable and definite in operation, are being produced in this country.

It is contrary to the regulations in this country to have a solid connection between feeders, and has been so for the last 30 years. The old Board of Trade Regulations required what is equivalent to a low-rated fuse at an intermediate point between the feeders. Someone among our officials must therefore have foreseen a good many years ago the trouble that has come through solid connection in a so-called low-voltage grid.

Also underground substations, which are referred to in the paper, are in this country allowed only in extreme cases where there is no means of putting substations above ground.

I should welcome some particulars of the non-return switch which prevents feeding-back from the low-voltage to the high-voltage side in the event of trouble. I am interested in the use of compressed air instead of solenoids for the operation of switches, particularly in view of the saving of over 40 per cent in the cost of the switchgear which is claimed on this account. I am also keenly interested in the remote-control system interconnecting the high-voltage-side fault, as it were, and the low-voltage switchgear. A similar arrangement is used on motor-convertors so that when the high-voltage side fails the low-voltage side is cut off from the general system, but I did not know that the idea had ever been applied to long-distance control.

Mr. H. Bannister: The author says that 250- and 160-kVA distribution substations are usually housed in the cellars of houses and factories. With underground substations there is always danger of flooding, and it would be of interest to know whether the German engineers take any special precautions against this risk. Also, do they take any special precautions against fire?

I should be interested to know what system of cable-laying is employed in the congested areas. Is a similar system adopted to that which prevails in New York, whereby the various services of the city make use of common subways?

Finally, can the author say whether, generally speaking, the efforts of the German engineers have resulted in cheaper electricity than we have in this country?

Mr. C. Kibblewhite: I should like to ask the author whether the low-voltage grid described in the paper is a reinforcing network superimposed on existing low-voltage networks or whether it is an entirely new network developed side by side with existing networks. If the grid is superimposed on existing networks, does not a difficulty arise in interconnecting parts of the network supplied from existing 6-kV sources with other parts supplied from new 33-kV sources? If, on the other hand, a separate new network is being developed, is it intended to abandon the practice of obtaining substation sites in consumers' premises and to feed the network entirely from the company's own substations? If so, the layout (400-kVA transformers and 4-core 0·15/0·07-sq. in. l.t. distributor cables) does not seem sufficiently generous for urban conditions. Supplies to large blocks of flats, offices, etc., are most readily given direct from the e.h.t. network, and I think it is essential that an urban distribution system should be readily adaptable to this practice. Distribution at 33 kV does not appeal to me for the purpose, and I much prefer the 6-kV or 11-kV systems which have proved very adequate in large towns in England where conditions must be very similar to those in Berlin.

The author mentions that all low-tension mains are tested once a year; how is this done, and is it necessary to disconnect the supply to consumers while the test is being carried out? I should also like to ask what type of network boxes, if any, are installed on the low-voltage grid. My experience of the behaviour of network boxes which have had to undergo heavy through fault currents on low-tension networks leads me to feel that a very robust type of box would have to be used to stand up to the strenuous conditions on a network on which it is intended to clear faults by burning out the cables.

It is interesting to note from Fig. 4 that the bulk supplies, which I take it are those given to large industrial consumers, are separated from the public supply networks. This practice has been adopted in certain large industrial towns in England with the object, presumably the same as in Berlin, of ensuring that trouble on an industrial consumer's high-tension plant, which cannot always be so rigorously inspected as the undertaking's own plant, shall not spread to public supply networks.

Dr. P. Dunsheath: I should welcome in this paper some more detailed reference to the underground system, and particularly the cable construction, from the standpoint both of the cable manufacture and of the methods of laying adopted.

There is one cable question which I think calls for some explanation. Table 2 gives a record of 30-kV cable failures: in 1929 there were 13, and they diminished year by year to 10, 3, and 1 respectively, until in 1933 there were no failures whatever. In 1934, however, there were 2, and in 1935 there were 4. I should like to know what happened in 1933 which suddenly changed the trend of this curve. On page 316 the author says: "Very valuable work has been done by the company's cable-research department in studying the characteristics of cables, as a result of which the number of failures on over 600 miles of 30-kV cable has been brought very low." It would be interesting to record when this research department commenced to function, and how its activities are related to the form of the curve. It may be that there is some definite explanation for the incidence of failure, such as a relaxed specification, or that in the natural development of the system the cables are being more heavily loaded than they were formerly. Another possible explanation is that a type of cable which fails after a number of years in service is now coming to the time when its troubles are beginning. In any case, this history of 30-kV cable performance is so different from that of other countries that some explanation would be useful.

Mr. W. J. Jeffery: Mr. Fennell mentioned that the conditions in Berlin are apparently entirely different from those in this country, particularly with regard to the development of underground substations. I should like to point out that the underground substation is not uncommon in London, and unfortunately in some parts of London it is very unlikely that any but underground substations will be built, at any rate for many years to come.

It seems to me that one of the advantages of the Three-Voltage System as compared with the Two-Voltage System is that with the former the cost of the high-tension switchgear in the transformer stations becomes more reasonable in proportion to the total cost of the equipment in the station. For example, I should have thought that in a 400-kVA substation the cost of 33-kV switchgear would be abnormally high.

I cannot understand the development in Berlin with regard to the low-tension network; on page 315 the statement is made that the 380/220-volt mains consist of "3-core banded cables." Does this mean belted cables? Did the success which attended the solid connections on the Berlin network depend on the size of these cables? Would there have been equal success if, for example, the low-voltage cables had been of 0·25 sq. in., 0·3 sq. in., or 0·4 sq. in.? Apparently tests were carried out on these cables, and I should like to know whether there is a possibility of such tests being carried out in this country. I should be very interested to see a short-circuit on, say, a 0·3-sq. in. 4-core conductor, and see the arc extinguished in a few cycles. In view of the fact that the engineers of the Bewag are stated to be quite satisfied with the solid-connected l.t. network, further information seems to be needed as to why they are now proceeding with the installation of fuses on this network.

Mr. B. A. Saddler: This paper is of particular interest to me because the supply system in Berlin has certain points similar to those of a supply company in which I am interested in Adelaide. There the tendency is to change over to the Two-Voltage System, cut out the intermediate 7·6-kV substations, and supply low-voltage (400-volt) networks directly from 33-kV lines.

About 1931 the problem of changing over to a solidly-connected low-tension network was investigated. No information could be found as to the possible consequences of such a change on a system operating at 400 volts or thereabouts, except the results of tests carried out in Germany on 380-volt systems. It was therefore decided to carry out some tests to ascertain the possibility of self-clearing of faults on low-tension cables. We operate on 0·3- and 0·5-sq. in. cables, and, as these represent quite a large capital investment, it is impossible to scrap them and change over to smaller cables. A series of tests was carried out on the 0·3-sq. in. and 0·5-sq. in. conductors, and out of 33 valid tests 5 (or 15 per cent) failed to clear. We found that there was never any doubt about clearing a phase-to-sheath fault, but that the 3-phase faults were a different matter. A phase-to-phase underground fault invariably spread to a 3-phase fault.

When we opened up the trenches containing these cables it was found that a metallic encrustation had formed in the earth around them. This mass of fused earth, copper, lead, and steel, had tended to prevent hot conducting vapour from escaping through porous earth, and the arc could not quench. In the case of the Berlin system the cables are of 0·15 sq. in. and the copper section is small with respect to the amount of insulation, and therefore one would expect the arc to clear more easily than with the large section of copper embodied in 0·3-sq. in. and 0·5-sq. in. cables. We found that the earth surrounding the arcing cable had acted as a condenser for the vaporized metal, and in some cases liquid copper and lead had dripped back on to the cores, tending to prevent the fault from clearing. In the case of cables in ducts, we found that the cable had been destroyed for quite a considerable distance behind the arc, owing to the fact that the heat produced had not been able to get away, and the sheath had been melted and the insulation charred. In some cases the copper cores were found embedded in lead.

We also made up a few lengths of test cable of 3-core 0·3-sq. in. section (copper equivalent). One core was pure copper, one half copper and half aluminium, and the other pure aluminium. Faults put on these cables cleared quite easily in a few cycles, even when the cables were laid in ducts. The explanation was that the different rates at which the aluminium and the copper burned back allowed the arcs to be drawn out and extinction to take place.

The results of these tests and of those carried out in Berlin seemed to indicate that, for satisfactory self-clearing of faults, the section of copper conductor should not be greater than 0·15 sq. in. I note that in Berlin cables insulated for 1 000 volts are used, thus providing greater spacing of cores and also a higher ratio of insulation to copper than with the normal 500-volt cables.

With regard to what the author says on page 315, in the Three-Voltage System, in the event of the high-tension circuit breaker opening owing to the temperature relay in the transformer operating, is there any means by which the network protector or automatic switch is opened? It seems to me that the transformer might remain excited from the low-tension network if the transformer fault was not great enough to cause 100 per cent reverse load, at which the reverse-power relays trip.

I believe that the Americans have had a good deal of trouble with the "pumping" of network protectors. The effect is due to the voltage of the incoming transformer slightly lagging in phase behind the network voltage. Phasing relays have been fitted so that the relay will not close the protector until the voltage of the incoming transformer is slightly advanced in phase compared with the network voltage. Has any trouble of this sort been experienced in Berlin?

I should like to ask the reason for using the 4-core pilot-cable arrangement on the Two-Voltage System. It seems rather expensive. What was the objection to using the American system of master relays for controlling the operation of the automatic network protectors, whereby the protector opens when there is reversal of power and closes again when the voltage of the incoming transformer is correct in magnitude and slightly advanced in phase with respect to the network? It seems to me that it would have been cheaper to use that system than to put in pilot cables.

Mr. J. I. Bernard: At the beginning of the paper the author refers to the Bewag having paid particular attention to the sale of electric cookers and water-heaters, in order to obtain a reasonable diversity factor for the domestic load. It would have been better if he had contented himself with pointing out that there is little space-heating load to be had in Berlin because of the prevalence of central heating, and that the bulk of the domestic load is therefore to be obtained from cooking and water-heating. Actually, of course, the load characteristics of cookers and water-heaters are better than those of space heating.

The question has been raised of how the cost of electricity in Berlin compares with the cost in this country. I had an opportunity of looking into this last year as far as domestic use is concerned, and I found that, generally speaking, the Bewag tariffs were rather higher than those in this country. When one takes into account the lower standard of living in Germany, particularly at the present time, I think that there is no doubt that electricity is rather more expensive over there. This may be partly due to the fact that until recently electricity in Berlin had been thought of largely in terms of lighting only for domestic purposes. Until about 3 years ago the Bewag concern and the gasworks were both owned by the municipality. About 3 years ago an interest in the Bewag was sold to private enterprise, and the control passed out of the hands of the municipality; the interesting point is that whereas up to that time there had been almost no electric cookers in Berlin, about 25 000 electric cookers have since been sold there.

Mr. W. E. Highfield: I believe that German engineers have almost discarded the oil switch and have concentrated on an air-pressure switch, which surely puts the question of underground stations on quite a different footing. The Berlin system also makes use of the Petersen coil and of several other outstanding developments. The success of this system hinges on half a dozen or more technical decisions and inventions.

There is one point which appeals to me particularly, and that is the effort to provide some source of energy from storage. I refer to the Charlottenburg station, where by means of steam accumulators it is possible to produce anything up to 40 000 kW. Such a system of storage is an enormous advantage to the supply engineer. German engineers have made another effort to produce a similar effect, not in Berlin but in Hamburg, where in the form of very large Diesel engines of 10 000 kW output they have an almost instantaneously available source of energy to add to the supply when it is required.

Mr. M. W. Humphrey Davies (*in reply*): The plant at Charlottenburg, to which Mr. Marshall refers, is one of the largest peak-load plants on the Continent. Its main purpose is to provide a reserve supply if the 100-kV transmission lines should fail, enabling the margin of standby plant on the busbars in Berlin to be reduced. But it has also proved useful in meeting unexpected demands and in helping to reduce the system peak. The sale of steam for heating appears to be a profitable proposition and the load is developing steadily.

The 30-kV grid was introduced in 1924; previously the system had been operated in two sections tied over the 110-kV lines. The voltage was fixed at 30 kV because that was the highest voltage for which cables were available. The cables (see Figs. 4 and 8) form a solid interconnection between the generating stations. The 30-kV grid was designed for an ultimate load of 1 million kVA, but it was realized that some form of interconnection at a higher voltage would eventually be necessary, and plans for the construction of a 100-kV ring were prepared. The need for this ring has not yet arisen; but when the load becomes excessive, it will doubtless be constructed and the 30-kV grid may be divided into sections. The subdivision of the low-voltage grids, about which Mr. Marshall inquires, was a result of the Three-Voltage system; each grid covers the area allotted to a single distributing station.

It is extremely difficult to estimate the relative number of switches in London and Berlin. The whole Berlin area, with its combination of urban and rural districts, is not unlike the whole South-Eastern Section of the British grid. But the latter is very much larger and, with its peak load of 1 500 000 kVA, is well past the limit set by the Bewag engineers to their 30-kV grid. The bulk of the power for the South-Eastern grid is generated in the larger stations, the smaller stations being reserved for peak-load working. The larger stations are interconnected by the main transmission lines (132 kV), which thus correspond in function to the projected high-voltage ring around Berlin. In the London area a secondary (66-kV) system takes the place of the 30-kV grid in Berlin, and the smaller generating stations may be regarded as the counterparts of the "distributing stations." An important feature of the British system is the provision of some generator capacity at each "distributing station," thus reducing the size and cost of the transmission lines. It would not do to push the comparison too far, but one can see that in general the voltages and distances are somewhat greater in London. The main transmission systems in Berlin and London appear to be well suited to their respective areas, and I think it is in tackling the problem of distribution from the local stations that the principles adopted by the Bewag are most interesting. There are four distinct features of outstanding importance, the division of the network into sections each fed from its own "distributing station" (50 000 to 100 000 kVA), the 6-kV interconnected radial system of distribution included in the Three-Voltage system, the successful construction of 380/220-volt grids in urban areas, and the experiments in the use of as high a voltage as 30 kV for feeding the low-voltage networks. These are all independent developments which should not be confused with one another, and, though Berlin itself is a large city, they are in part applicable to much smaller towns.

As Dr. Stritzl states, Petersen coils are very widely used on cable systems in Germany. Stuttgart, Hamburg, and Munich, may be cited as particular examples. In Hamburg the coils are at the generating stations, but in Berlin they have been placed in the distributing stations for convenience. The earth-fault current, which is reduced to about 100 amperes, operates a zero-phase watt relay which clears the cable. This system works very satisfactorily, provided the Petersen coils are evenly distributed. Automatic tripping, though used in Berlin, can be dispensed with—giving the operating engineer time to readjust his feeder arrangements before taking the cable out of service. With Hochstädter or three-lead-sheath cables earth faults rarely become inter-phase short-circuits.

In the 30-kV network and the part of the 6-kV network where there are duplicate feeders, single-phase impedance relays are used exclusively. The 30-kV cables have one relay in each phase, but the 6-kV cables have relays in two phases only. Pilot protection is only used where a 6-kV substation is housed in the same building as the distributing station, and impedance protection would be impracticable. Pilot cables are laid alongside most of the feeder cables, but these are used solely for telephones and signals.

The 24 sections referred to in the paper were in existence before the low-voltage grids were constructed; they are the sections of network corresponding to the 24 distributing stations, and only the central ones have been converted into grids.

The choice of the limited area in Berlin was not based on any considerations of stability. The construction of a single low-voltage grid by interconnecting the different "distributing station" areas was made impossible by the parks and canals and the isolated sections of d.c. network which divide the city, and by the fact that the method of voltage regulation differs in the different distributing stations, some of which are equipped with phase-shifting regulators. Grids somewhat larger than 2 square miles would probably be equally satisfactory, but it is advisable to set some sort of limit in order to avoid the difficulties experienced in America, where the whole network was connected into one grid. It is not possible to say yet how large the networks in Berlin will become. With the present arrangement it is claimed that each section of network can be switched in or out independently and without difficulty. The claim that low-voltage grids are more economical in areas of large load-density is based on a careful investigation of costs which is referred to in Reference (10) in the Bibliography. Further information regarding alternative systems and their design is given in a recently published work by Dr. Menny of the Bewag.*

I must thank Mr. Ambrose for pointing out the error in Fig. 5. The error, which was in the key diagram, has now been rectified. Fig. 4 is a schematic diagram of the two systems used: the Three-Voltage System is shown on the left and the Two-Voltage System on the right. The connecting link shows that the regulation in the two systems is not necessarily the same. In practice, both systems are supplied from the same station busbars and are used to feed common networks. In order to give each network the same regulation, the 30/·38-kV transformers have been given a higher impedance than is usual. If necessary, the 30/6-kV transformers, which are either fitted with on-load tap-changing gear or are of the "sliding-core" type, can be adjusted. As explained on page 313, the reactances are used to limit the fault kVA to 300 000 in the 30-kV and 120 000 in the 6-kV networks, respectively. At the time the network was being constructed, the high-capacity switch was still in its infancy and this was the more economical method. It is perhaps worth noting that it is the general practice in Germany to raise the generating-station busbar voltage considerably during periods of heavy load.

It is not yet clear how far the Bewag intends to proceed with the construction of a Two-Voltage system. The existing Two-Voltage network in Charlottenburg is very small and is in a sense experimental. Should the Two-Voltage system be more generally adopted, the company would not scrap the cables and substations of the 30/6-kV system, but would continue to use them for supplying the rectifier stations for the electric railways and for supplying those large consumers who could be supplied more economically at 6 kV or higher voltages. The question of continuity of supply is more economic than technical, and the final decision is not always in the hands of the engineer. In Berlin, continuity is very highly valued, and no effort has been spared to achieve it. The protection of the Three-Voltage system is the result of a number of years of research and experience; it is not excessively complicated and is apparently satisfactory. The Two-Voltage system represents a considerable step forward towards a *simple* system, and has the additional advantage of a high continuity factor.

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* "The Economic Dimensions of Urban Three-Phase Distribution Networks" (Postberg, 1935).

The satisfactory operation of a fused low-voltage grid depends largely on the type of fuse employed. Provided the feed points are sufficiently numerous and evenly distributed, the highest current will flow in the faulty cable. For satisfactory operation, the fuse must have a marked time-characteristic to enable it to distinguish between the current in the faulty cable and those in the neighbouring cables. The current in the Bewag grids is limited to 18 000 amperes, and the fuse has the characteristic given on page 316.

The automatic switch used in the 6/·38-kV substations, about which Mr. Fennell inquires, is the main factor upon which the satisfactory operation of the low-voltage grids depends. The Bewag switch differs slightly from the American type. It consists of a 3-pole air-break switch fitted with arc-chutes and housed in a pressed-steel box, which also contains a single-phase motor supplied from the low-voltage mains, and a combined closing and tripping relay. The switch can be operated by hand if necessary. The switches have no protection against pumping, but a counter is fitted which records the number of times the switch operates. The short-circuit voltage of the 6/·38-kV transformer is about 4 per cent, and the switches are rated to break 20 times the rated full-load current. The switch is tripped by a reverse-power relay. In the early switches this was set to trip on a very low reverse current and pumping was frequent, so the relay was replaced by one in which the setting depended on the voltage; with full voltage the switch trips at 1·2 times full-load current, but if the voltage drops to 10 per cent of normal the current setting drops to 0·3 times full-load. Overloading of the transformer is prevented by the temperature relay which trips the 6-kV switch if the transformer gets too hot. In the early switches the closing relay compared the transformer voltage and the network voltage, and closed the switch when the transformer voltage was the greater. This relay has now been replaced by a simpler one which closes the switch when the transformer voltage is 85 per cent of normal. The switch is said to be quite satisfactory. In order to ensure isolation of small transformer faults, the switch is interconnected with the 6-kV circuit breaker; if the latter opens, the automatic switch must open too. The same switch is used in the 30/·22-kV substations, but the relays are dispensed with and the switch (see Fig. 12) is controlled by the main circuit breaker in the generating station, whose motions it follows.

The reduction in the cost of substations with compressed-air-operated water-switches is largely due to savings of space and reduction of installation and maintenance charges, by the reduction in the size of the batteries and the simplification of the control circuits. Further details are given in Reference (22).

The cellars which house the 6/·38-kV transformer stations, referred to by Mr. Bannister, are of the semi-basement type in which there is little danger of flooding. The 6-kV cells are of a standard open busbar construction and no special precautions are taken. In the larger substations (30-kV and 6-kV) busbar sections are housed in different floors but the phases are not separated. The tanks of the oil switches hang in the open or in a special corridor equipped with oil drains, CO_2 equipment, and ventilating gear for removing fumes. The only substations which are really underground are equipped with ironclad gear; the experimental 30/·38-kV stations shown in Fig. 6 have watertight gear designed to operate even under water. All substations are supplied with sand buckets, etc., and the potential and current transformers installed in recent years are insulated with non-inflammable materials. Pyranol has not been employed for power transformers, but they are equipped with Buchholz relays to detect and clear incipient faults.

Subways are not used at all in Berlin. In most streets the sewers are under the roadway on either side of the underground railway, which runs immediately below the tramlines. The pavement is divided into sections which are allocated to the post office, the fire brigade, and the gas, water, and electricity authorities, who are allowed to dig to any depth in their allocated area. The pavement usually consists of small sets and the soil is very sandy. Coal chutes are fortunately non-existent. The Bewag cables are laid in the ground and protected by an arched clay cover which fits closely to the upper part of the cable. Ducts are only used at important crossings and are made of moulded asbestos (for d.c. cables) or iron (for 3-phase a.c. cables).

The low-voltage grids have been formed without laying any extra cables, by connecting up the ends of the existing cables. The Bewag system is not very different from that advocated by Mr. Kibblewhite. It might almost be called an extension of it in which the dead ends of the cables from adjacent transformer boxes are connected together. Transformer stations, supplied through 6-kV feeders, are situated in the centre of or between blocks of offices. Until the grid system was introduced, power was transmitted to the services and rising mains in the buildings by radial feeders. The transformer stations usually contained two transformers, each of which was capable of supplying the whole load. Because of the small size of the transformers and the shortness of the low-voltage feeders, the system was virtually a 6-kV distribution network with low-voltage services. The reserve transformer capacity was about 100 per cent. (If a similar network had been laid out in England, it would probably have been necessary to use larger cables because of the heating load, which is absent in Germany.) To form the low-voltage grids, the dead-ends of the cables in adjacent blocks were connected together. This not only improved the regulation of the whole network, but it made possible the reduction of the total reserve transformer capacity to 33 per cent, thus increasing considerably the capacity of the existing network.* The Two-Voltage system is still in the experimental stage, and, as can be seen from Fig. 8, the existing 30/·22-kV stations only supply a small portion of the load for their section. By using transformers with a slightly higher impedance than usual, the regulation has been made approximately the same as that in the Three-Voltage system.

With the low-voltage grids an open circuit in a main causes no interruption of supply unless it occurs at a service junction. It is possible, however, that the consumer's voltage may drop somewhat. The Bewag has found by experience that faults which are serious enough to require attention are always detected by the consumer; the rest are left until the annual test. This is a simple continuity test; one end of the cable is disconnected and the voltage between cores is measured. This does not involve any interruption of supply. Routine insulation tests of the d.c. cables are also made from time to time, and then, of course, the feeder must be isolated. The network boxes are all of a cast-iron type with ring-form busbars. The object of keeping the industrial supplies (6-kV) separate from the public supply networks was chiefly to render the factories independent of any trouble in the low-voltage network. In practice it has not proved economical to do this to any large extent, and many factories receive their supplies from the 6-kV rings that feed the low-voltage network. As the Two-Voltage system develops, the 6-kV mains will still be used for industrial supplies.

In reply to Dr. Dunsheath, the first 30-kV network in Berlin was completed in 1912. Three-core belted cables were used. Hochstädter cables were introduced during the construction of the 30-kV grid, but since 1932 triple-lead-sheath cables have been used because of their greater heat conductivity, which enables them to be operated at a higher current-density. All three types of cable are said to be giving satisfactory service. The 6-kV cables are of the belted type. Until recently the 1-kV cables used for the low-voltage network were also belted, but a triple-lead-sheath cable has been adopted for the new low-voltage grids because it will clear faults with higher currents than the older type. Cables are normally waterproofed and armoured. The soil being sandy, they are laid in open trenches and covered with arched earthenware covers fitting closely to the top half of the cable. This type of cover is comparatively cheap and has been used for some years.

The cable-research department was founded about the middle of the last decade at a time when newly-laid cables did not appear to be as good as one might expect. The success of the department is most clearly seen in the improved power factor and ageing qualities of the cables manufactured to its specifications. The department has also collected a considerable amount of information regarding the performance of cables in service. Table 2 was intended to show that the annual number of faults was very low. Of the 4 faults in 1935, 2 were due to mechanical damage by excavators. If these 2 faults are neglected, the average for the last 5 years is 2 faults per year in 600 miles of cable, some of it many years old. In 1936 there was one fault in the first 8 months. This appears to me to be a very low figure, and I do not think one would be justified in claiming that the history of 30-kV cable performance is any worse in Berlin than it is elsewhere.*

I agree with Mr. Jeffery that conditions in Berlin are not unlike those in London; the Bewag do not build underground substations unless these are essential. One of the advantages of the Two-Voltage system is the elimination of much switch and control gear. It will be seen in Fig. 12 that the only large circuit breaker is that at the end of the 30-kV feeder. The 30-kV switches in the substations (see also Fig. 6) are comparatively inexpensive hand-operated isolating switches capable of breaking the normal full-load current only.

The majority of the 380/220-volt cables are belted lead-covered and armoured cables insulated for 1 000 volts. Cables having separate lead sheaths on each core are being adopted as far as possible for the low-voltage grids because they can break heavier currents. The capacity of a cable to clear a fault on itself depends more on the voltage than on anything else. There is an upper and a lower limit to the current which the cable can interrupt; if the current is too great the cable burns back rapidly to the nearest junction-box; if, on the other hand, the current is too low to form a good arc, the cable smoulders indefinitely. The limiting values of current depend mainly on the voltage, but are also affected by the nature of the cable itself, the thickness of insulation, the amount of copper in the cable, and the soil in which the cable is laid. For satisfactory operation at 380 volts, cables must be laid in the ground and not in ducts, but the presence of short lengths of ducting does not render the system impracticable [see Reference (8)].

I was very interested to hear of Mr. Saddler's researches in Adelaide† and to learn that 0·5-sq. in. cables insulated for 600 volts had been able to clear 85 per cent of the faults on test. The method of applying the faults to a cable by an artificial pick-stroke was ingenious and differed from that in Berlin where the faulty cable was switched on to the mains. In the Berlin tests the normal Bewag cables—3/·15 + 0·07 sq. in., with 1·5 mm of insulation between cores, the voids being filled with impregnated jute, covered with 2·4 mm lead, and double-armoured with 0·8 × 50 mm strip—were laid in sand at a depth of 2 to 3 ft. and covered with clay covers. They cleared all of 26 short-circuits under 18 000 amperes, but failed in 9 cases out of 33 when the current was greater. Specially-constructed cables were able to clear still heavier currents. Tests were not carried out on cables of a greater section than 0·15 sq. in., or at higher voltages than 380. The tests showed that high gas pressure, good heat conduction, and the use of non-inflammable insulation, hastened the quenching of the arc by hindering restriking. Single-phase faults are easier to clear than 3-phase faults, and it appeared that the copper tended to burn more rapidly than the insulation. If three-lead-sheath cable is used all faults will tend to be virtually single-phase.

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* See footnote on page 322.

* See *Elektrotechnische Zeitschrift*, 1936, vol. 57, p. 1401.

† *Journal of the Institution of Engineers, Australia*, 1933, vol. 4, p. 8.

Table A

COMPARISON OF LOW-VOLTAGE SUPPLY TARIFFS IN LONDON AND BERLIN

Nature of supply	BEWAG			London and Home Counties Joint Electricity Authority (Inner Zone)		County of London Electric Supply Co.			
						Finsbury Area		Essex Act Area	
	Tariff number	Quarterly fixed charge	Cost per unit	Quarterly fixed charge	Cost per unit	Quarterly fixed charge	Cost per unit	Quarterly fixed charge	Cost per unit
Domestic :—		marks	marks	shillings	shillings	shillings	shillings	shillings	shillings
Lighting, flat rate	II	None	0·40	2·0 to 5·0*	0·42	*	0·42	*	0·66
Lighting, two-part tariff	I*c*	See below	0·20	—	—	—	—	—	—
Heating	V	None	0·08	2·0 to 5·0*	0·22 to 0·08	*	0·12	*	0·17
All-in, two-part tariff	I*b*	See below	0·08	See below	0·08 to 0·04	Fixed charge	0·04	Fixed charge	0·08
Business :—									
Lighting, two-part tariff	I*a*	1·05/100 W	0·20	5·0/100 W installed	0·06 to 0·04	5·0/100 W (light)	0·04	7·5/100 W installed	0·08
Heating, two-part tariff	VIII	3·0*	0·08 to 0·06						
Power, two-part tariff	—	—	—	14·0 to 8·0/H.P.	0·06 to 0·04	—	—	—	—
Power, sliding-scale tariff	—	—	—	—	0·21 to 0·08	—	0·21 to 0·06	—	0·27 to 0·06
Power and lighting, two-part tariff (at least 70 per cent power)	IV	1·05/100 W (light) + 0·30/100 W (power)	0·16 to 0·08	—	—	—	—	—	—
Special Tariffs :—									
Off-peak supplies:—									
Water heaters	III	1·50*	0·04	—	—	*	0·04	*	0·06
Battery charging						*	0·06 to 0·04	*	0·06 to 0·04
Reserve supplies	VII	According to cost of supply	0·20	—	—	—	—	—	—

	Tariff number	Number of rooms					Floor area (sq. ft.)		
	I	1	2	3	4	5	800	1 000	1 500
Quarterly fixed charges for domestic two-part tariffs	I*c*	2·40	3·00	4·50	6·90	9·30	—	—	—
	I*b*	4·80	6·60	9·00	12·75	17·25	10·0	12·6	17·7

Current rates of exchange

At par of exchange 1 Reichsmark = 1·00 shilling
On the 8th October, 1936, 1 Reichsmark = 1·64 shillings
1d. = 0·083 shilling

Minimum hourly wages in Germany

	marks
Electrical fitters for machinery and switchgear	0·93
Linesmen for outside work	0·82
Wiremen for house-wiring	0·72

The figures for the London undertakings are taken from the 1934–35 returns for the London and Home Counties Electricity District.
The Bewag area of 360 square miles is made up as follows: Urban 28 per cent, semi-rural and rural 45 per cent, lakes and forests 27 per cent.

* Meter rent, etc.

Most of the speakers in the discussion seem to have had doubts about the stability of the low-voltage grids, especially when connected solid. When the grids were first planned in Berlin, the tests on burning-out cables were not complete. It was for this reason that fuses were introduced in the early networks. At the time that this paper was written no definite decision had been reached, but experience appears to have shown that fuses are unnecessary, and I am informed that in future all new low-voltage grids will be connected solid. At present there are 8 separate grids in Berlin, and of these only the first three to be constructed had fuses. The only fuses in the new networks are high-capacity " carrier " or " long-time " fuses, fitted in the leads from the low-voltage side of the transformer. These are intended to act as safety devices should the automatic switch fail to clear a heavy fault current.

The question of " pumping " was referred to in the reply to Mr. Fennell. The difficulty appears to have been overcome in a comparatively simple manner. The fact that each network is limited in area and is supplied from a single distributing station helps considerably to reduce equalizing currents. It will be interesting to watch developments as the Two-Voltage system is extended. One of the main advantages of the pilot system of protection for the Two-Voltage system is that the protective relays on the transformers (Buchholz and temperature) can operate the main circuit breaker, thus making it possible to eliminate all other big switches. The 4-core pilot is common to all stations on the cable. The low-voltage automatic switch has no measuring relays of its own, but follows the movements of the main breaker. It is possible that a still simpler method can be devised.

The lack of a reasonable space-heating load is more important than Mr. Bernard supposes. Domestic electrification is much more widespread in Germany than with us; in the Bewag area 83 per cent of the houses and flats had electric light in 1935, and yet the domestic consumption per head of population is considerably less than it is in large English towns. Some increase in storage heating is to be expected, but central steam-heating is likely to retain its place for many years. The chief effects of this lack of heating load are seen in the cable dimensions and in the tariffs. The Bewag tariffs are summarized in Table A, and it will be seen that there is no real domestic power tariff. It is difficult to find a basis for comparison with English prices; the best rate of exchange is perhaps one based on the rate of pay of an electrical fitter (see Table A), but even here there are differences, e.g. in insurance and travelling expenses, for which it is difficult to allow. (In general, transport is very cheap in Germany.) In comparing tariffs, one also has to bear in mind the cost of coal and copper, which is higher in Germany, and the fact that most power companies pay a fixed annual sum to the local government authority for their concession, in addition to their rates and taxes. In Berlin this amounts to about 0·1d. per unit. The Bewag tariffs compare favourably with those in other German towns. When one remembers that nearly half the Bewag area is semi-rural and that a uniform tariff is charged for all districts, I do not think one can claim that the Bewag tariffs are unreasonable.

The financial history of the Berlin supply system is very interesting, and is worth the attention of anyone interested in the reorganization of urban supply systems. The original company, founded in 1883, was a private one, but, at the conclusion of the first concession period in 1915, the city exercised its right of purchase. From 1915 to 1923 the company was operated by the city authorities. This method was not entirely successful, as the company was apt to be exploited for political or financial ends. At the end of 1923 the city authorities floated a subsidiary company to operate the concern, retaining the capital and buildings in their own hands. The company was thus freed from political influences and it was at this time that the period of rapid development set in. The organization appears to have been entirely satisfactory, but for financial reasons a semi-private holding company was formed in 1931. This company, called the " Berliner Kraft- und Licht- A.G." acquired all the assets and liabilities of the Bewag, as well as the power stations and other properties which had belonged to the city authorities. The capital was fixed at 240 million marks (RM.) and the shares were divided so that one half of the voting power was in private hands and the other half in the hands of public concerns, the City of Berlin, the " Elektrowerke A.G." (owned by the German Government) and the " Preussischen Elektrizitäts A.G." (owned by the State of Prussia). At first the Bewag was retained as an operating company, paying the whole of its working profit to the holding company, but at the beginning of 1934, in order to simplify the management, the two companies were merged to form the Berliner Kraft- und Licht- (Bewag) A.G. Experiments with electric cookers were commenced in 1927, and the first big sales campaign was in the spring of 1932. There are a number of other semi-private undertakings of a similar nature in Germany.

As Mr. Highfield suggests, the " oil-free " switch is rapidly replacing the oil switch in Germany. These switches are of two types. One is known as the " expansion " or " water " switch; it is an explosion-pot switch in which the pot is filled with a mixture of water and glycerine. The other is the " compressed-air " switch in which air at about 10 atmospheres is used to blow out the arc. Both switches need to be opened and closed as rapidly as possible and should be interlinked with an isolating switch. Another achievement of considerable importance is the development of non-explosive current and voltage transformers, to which reference has already been made. The successful use of Petersen coils to eliminate heavy earth-fault currents, though not confined to Berlin, is also worth stressing, as well as the simplification in the protection of distribution transformers by Buchholz relays. But it is in the planning of the network that the Bewag is of supreme interest. The low-voltage grids have certainly proved their worth, and the Two-Voltage system, if it is successful, should prove an economical method of supplying them. The 6-kV distribution system, an excellent system where security of supply is desirable, is a good example of the careful planning one has learnt to expect from German engineers.

DISCUSSION ON

"RECENT PROGRESS IN INDUCTION-MOTOR CONSTRUCTION"*

WESTERN CENTRE, AT CARDIFF, 9TH NOVEMBER, 1936

Mr. D. J. Thomas: The author's reference to end-shields raises the question whether end-shields are not made much weaker on motors fitted with ball and roller bearings in comparison with those fitted with sleeve bearings. Experience has shown that modern motors fitted with ball and roller bearings have given trouble in situations subject to vibration to a greater degree than those fitted with sleeve bearings. This is attributed to weaker end-shields giving much less mechanical rigidity, which is indicated in slip-ring and brush troubles. Owing to vibration the brushes do not make good contact with the rings, and this causes slight pitting of the rings, which, once begun, soon increases rapidly. I should like the author to state how he deals with these troubles, and to what extent they are due to the inherent weakness of design of motors fitted with ball and roller bearings.

I am surprised to find that no reference is made by the author to the all-steel rotor fitted in modern machines; I should like him to express his views about this, and regarding the probable development and application of this type of rotor in the future.

Mr. L. F. A. Driscoll: It would appear that the main purpose of this paper is to advocate the welded or fabricated yoke and rotor form of construction as against the cast-iron types of machines, but it is surprising to find that no comparative curves of distortion or displacement of air-gap or other useful comparative data are given.

No reference is made to the weight ratio, and I should like the author to state what this would be for two similar-performance machines of, say, 500 h.p. Would the total unbalanced magnetic pull of three times the weight of the rotor quoted on page 390 amount to approximately the same value for both forms of construction?

From a transport point of view, rail charges would be lower for the fabricated machines, on account of their weight being less than that of the cast-iron types, and breakages should be considerably reduced.

Concerning windage and magnetic noises, can the author suggest any improvements to reduce these effects in small machines, particularly single-phase units up to 5 h.p.? Such machines at present leave much to be desired from the point of view of noise, especially in situations when the minimum of noise is essential.

Mr. C. F. Freeborn: What means is adopted to free a fabricated stator or bedplate of the stresses induced by welding; and is there any record to prove that welded structures do not alter their shape over a period of, say, 5 or 7 years?

Secondly, why does a winder or large haulage motor on which the stator is wound in open slots apparently produce greater wear on the reversing-switch contacts than a motor with closed or semi-closed slots?

Mr. H. G. Weaver: With regard to lifting arrangements, the five mentioned in the paper are much to be preferred to the bad practice occasionally met with, of welding a separate lug on to the outside of the frame. It is much safer to take the lifting strain by a definite cross-section of material than by an uncertain cross-section, depending on the skill of the welder.

I agree that the modern small induction motor is very inaccessible, and when trouble occurs it is quicker to replace the complete motor with a spare, than to attempt a repair. Fans on the rotor make it very difficult to get at the windings to clean them, and, even after dismantling, the windings cannot be cleaned easily, as they are usually tightly packed together in a limited space. This, together with the type of former-wound coil generally used, makes the replacing of a faulty coil very difficult, and usually necessitates a complete rewind.

The modern cartridge type of roller bearing has greatly assisted in the quick dismantling of a machine, and I have not come across a case of failure of such a bearing, even under severe conditions. There is a tendency, however, where roller bearings are used, to make the air-gap too fine, and I have known several cases where the rotor core has jammed in the stator core and stalled the machine, owing to dust packed hard between the cores, the normal air-gap being extremely small in each case.

White-metal-lined split-sleeve bearings are satisfactory in larger machines for heavy duty. The two main factors contributing to their freedom from failure are (*a*) oil wells which do not lose their oil, and (*b*) oil rings which do not stick. Trouble has been experienced with oil being sucked out of the wells by windage, in high-speed motors fitted with fans, but most makers appear to have overcome this difficulty.

Motors which are subject to considerable vibration, such as when driving gearing which has worn, sometimes give trouble due to the oil rings leaving their grooves. Usually one ring works its way into the other groove, and stops both rings working. In such cases a small removable strip fixed across the top of the groove has proved a satisfactory remedy. Another source of trouble is the joints of split oil rings. Sufficient care is not always taken to make the joints smooth and to keep the inside radius of the rings correct at these points, and sticking results.

Ventilating fans are sometimes of flimsy construction, and should be specially strengthened on machines which have to reverse frequently.

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* Paper by Mr. L. H. A. CARR (see vol. 78, p. 383).

I am surprised at the statement made in the paper that totally-enclosed double air-circuit machines are not acceptable for use in the heavy industries. This type was developed for heavy duty in dirty situations, and these are the conditions met with in the heavy industries, where such motors have been found very satisfactory. Although they are not so accessible as the standard type of machine, this is more than counterbalanced by the fact that it is not necessary to dismantle them for cleaning.

Among other causes of breakdown, the author mentions "surge on the system." I should like him to explain what kind of surge is referred to, the type of motor affected, and how the motor failed.

Mr. Reginald Robinson: I should like to suggest that the covers of slip-rings, whether of the pressed-steel or the cast-iron type, should be fitted with handles and also have some form of guide dowel to carry the weight and assist in guiding for centring the holes for the set-screws. As regards the pressed-steel type of cover, its shape in large sizes makes it difficult to fit, where handles are not fitted, and in the cast-iron type the added weight increases the difficulty. One frequently finds that no less than three men are required to replace a cover of the cast-iron type where used on a motor of 250 h.p.

In the journal-bearing types of motor a glass-inset inspection oil-rings cover is fitted, and I suggest that, whereas at present this is secured by a hinge at one end and has no properly-made cord-packing joint between the edge of the cover and the bearing housing, it would, for mining conditions, be much improved by the provision of some such type of jointing and a securing set-screw at the side opposite the hinge of the cover, so that dirt may not enter the oil-well by the careless replacement of the cover after the oil has been replenished.

Mr. L. H. A. Carr (*in reply*): Mr. Thomas has, to a large extent, answered himself by admitting that where trouble was experienced with ball and roller bearings the end-shields were weaker than those supplied with sleeve bearings. There is no justification, other things being equal, for making one end-shield weaker than the other. Consequently, as regards slip-ring and brush troubles due to vibration, there is inherently nothing to choose between ball and sleeve bearings, although as regards the bearings themselves the journal bearings show up better under vibration, any hammer blow being less concentrated, whilst, in addition, with sleeve bearings the oil film exerts a damping effect on the movements of the shaft. Where excessive vibration cannot be eliminated—elimination is of course the correct cure—it is frequently possible to avoid pitting of slip-rings and brushes by increasing the number of brushes per ring from 2 or 4 to 6, spaced evenly round the ring. This palliative can, however, only be adopted when the slip-rings are designed with sufficient margin to allow for the dissipation of the increased friction losses.

The machine with an all-steel rotor has inherently a low efficiency and a low power factor, for reasons which are clear to all designers of electrical machinery. Consequently, its use is limited to drives where these characteristics are relatively unimportant, in other words to drives where the running time is very short and where the advantages of higher starting-torque and ruggedness of construction are of great value. Motors of this type are used for starting rotary convertors, driving live rolls, and similar jobs where the duty is almost entirely that of starting, but on account of the above disabilities it is not to be expected that all-steel rotors will come into use for continuously-rated machines.

I cannot agree with Mr. Driscoll that the main purpose of the paper is to advocate welded frames as against cast iron. Either material can be used to produce a perfectly satisfactory yoke; and, as mentioned in the paper, for certain types of design the welded frame lends itself the more readily, for others the cast iron. No comparative curves of distortion are given because either type of yoke can be designed to meet the same figures, with very little difference either in weight or in cost between the two types. The unbalanced magnetic pull when the rotor is touching the stator is entirely independent of the material of which the frame is made.

Regarding the possibilities of eliminating to a large extent both magnetic and windage noises, nothing useful can be said at present, beyond the fact that manufacturers are fully alive to the problem and that a considerable amount of investigation is taking place on the subject.

In reply to Mr. Freeborn, low-temperature annealing or stress-relieving can be applied to a stator but, in general, is found to be unnecessary since no appreciable change in dimensions takes place, even over many years.

I regret that I cannot give any explanation of Mr. Freeborn's observation that machines with open-slot stators produce greater wear on the reversing switch-contacts than machines with semi-closed slots.

In reply to Mr. Weaver, it is very unusual to weld a lifting lug to the outside of a frame, and, where it is possible to examine a machine internally, it will usually be found that the lug forms the end of a bar which has been pushed through the wrapper plate. By welding this bar to the wrapper plate round the junction on the outside of the machine, it is impossible to tell from the outside that the lug is really only one end of a member carried right through from the interior.

Mr. Weaver is surprised at my statement that totally-enclosed double-air-circuit machines are not acceptable for use in the heavy industries. I can only say that this is the position as I find it. These machines are not yet generally acceptable to these industries. This is not to say that the position is the fault of the manufacturers or that the machines are unsuitable for such service, but they are just not used, and it is for the engineers engaged in these industries to adopt such machines for new installations in positions and for duties for which they may be suitable.

By the term "surge" is meant any abnormal voltage-rise on a system, whether due to lightning, switching operations, sudden clearance following a short-circuit, or any other cause extraneous to the motor. No specific breakdown was indicated; but breakdowns, principally in the stator winding, have been known to occur owing to the above causes.

I thank Mr. Robinson for his practical suggestions, which, it may be expected, will be considered by the various manufacturers of electrical machinery.

THE PERFORMANCE OF COIL IGNITION SYSTEMS, WITH PARTICULAR REFERENCE TO DOUBLE CONTACT-BREAKERS AND THE EFFECTS OF VARIATION OF THE PERIOD OF OPEN CIRCUIT*

By W. R. DEBENHAM, B.Sc., Associate Member.

(*Paper first received* 29*th May and in final form* 13*th October*, 1936.)

SUMMARY

The paper deals with experimental results obtained on a modern coil ignition system operated by a double contact-breaker with a small angle of open circuit. At high speeds the contact breaker closes before the spark discharge ceases.

Measurements of the effect of the persistence of the spark dicharge upon the coil performance for various secondary loading conditions are described. It is shown that the increase in the just-regularly-sparking output which is obtained is approximately independent of secondary loading due to normal values of shunted capacitance and/or resistance.

A theoretical investigation, based on the results, is carried out to determine the approximate increase in sparking frequency with a given output, due to the effect of the persistence of the spark discharge, for various periods of open circuit. Under certain conditions, the estimated increase is 35 per cent for 0·4 millisecond and 63 per cent for 0·1 millisecond.

The maximum sparking frequency of 12-volt coil systems, capable of meeting the output requirements of the Service specification for ignition apparatus, is estimated for various values of the open-circuit period. It is shown that the probable limit for reliable operation with a double contact-breaker is about 300 sparks per sec. per coil.

(1) INTRODUCTION

The limitation of high-speed performance of coil ignition systems is mainly due to the fact that the primary supply voltage is constant. The energy stored in the primary winding at the instant of break becomes progressively smaller as the period of closed circuit diminishes with increase of speed, and, with the limiting current determined by sparking at the contacts, the performance can only be improved, for a given voltage, by decreasing the angle of open circuit.

It is known that the limitation of high-speed performance of magnetos is not due to primary voltage, since this increases with increase of speed, but to the persistence of the spark discharge, which tends to retard the flux reversal and diminish the primary energy at break. In general, the sparking frequency can be increased by increasing the period of open circuit up to a limit which depends upon the position of the inductors relative to the armature poles. This position is dependent upon the low-speed performance required and the timing range.

It has been suggested by Finch and Sutton† that the sparking frequency of coil ignition systems can be increased considerably by the use of a double contact-breaker so disposed that the period of open circuit is only just sufficient to allow a spark to occur. By this means a considerable re-transference of energy from the secondary to the primary will occur when the contacts close, owing to the persistence of the spark discharge, in a period of time which can be neglected in comparison with the total period of closed circuit.

This paper deals with experimental results obtained on a modern coil system operated by a double contact-breaker with a small angle of open circuit, and an investigation, based on the results, into the effect of the persistence of the spark discharge and the variation of the period of open circuit. The probable ultimate limit of sparking frequency of 12-volt coil systems with a double contact-breaker, capable of meeting the requirements of the Service specification for ignition apparatus, is estimated. The output requirements of the specification may be briefly stated as follows: (*a*) Regular sparking at 9 000 volts with a capacitance of 250 $\mu\mu$F—equivalent to 6 ft. of screened h.t. cable—shunted across each spark-gap. (*b*) Regular sparking at 5 000 volts with a shunted capacitance of 250 $\mu\mu$F plus a shunted resistance of 0·2 megohm, the latter load representing the insulation resistance of a leaky sparking-plug.

(2) THE CHARACTERISTICS OF THE SPARK DISCHARGE

The theory and characteristics of the spark discharge of an ignition coil have been described by Finch and Sutton,† and by Bradford, Finch, and Prior,‡ who have shown, by means of cathode-ray oscillograms, that when the voltage which the ignition coil can produce considerably exceeds the breakdown voltage of the spark-gap the discharge consists of a high-potential spark—the "capacitance component"—followed by a low-voltage "pulsating" arc—the "inductance component." The capacitance component is a high-frequency oscillatory current of considerable magnitude, and has an extremely short duration of the order of 10^{-6} sec. The inductance component consists of a damped oscillatory current, superimposed upon a linearly decaying current. The current is unidirectional throughout the life of the inductance component. The total duration of the discharge may be as much as 6 milliseconds, but is dependent upon the reserve of voltage which is available. The larger the output voltage of the ignition coil in relation to the breakdown voltage of the spark-gap, the longer is the duration of the discharge.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† "The Control of Ignition-Coil Discharge Characteristics," *Proceedings of the Physical Society*, 1933, vol. 45, p. 288.

† *Loc. cit.*

‡ "The Ignition of Some Explosive Mixtures," 1933, Part I, p. 227; and 1934, Part I, p. 75.

When the breakdown voltage of the spark-gap is comparable with the output voltage of the ignition coil the discharge is extinguished in the troughs of the oscillations of the inductance component, each oscillation of which is then preceded by a capacitance component. The discharge in this case comprises a number of high-potential sparks each of which consists of a capacitance component and one, or part of one, oscillation of the inductance component. The current is unidirectional and decays linearly, but the discharge may be extinguished before the current has completely fallen to zero.

It was also shown, by means of oscillograms, that the closing of the primary circuit during the life of the discharge extinguishes the discharge in a period of time of the order of 0·01 to 0·1 millisec. During this period the primary current builds up rapidly to a value which is proportional to the average value of the unidirectional secondary current at the instant of the closing of the primary circuit. When the spark discharge ceases the rapid increase of primary current also ceases, the current building up during the remainder of the closed-circuit period at a much slower rate. For practical purposes the small period of 0·01 to 0·1 millisec. can be neglected in comparison with the total period of closed circuit, which is rarely less than 2 millisec.

The capacitance which discharges during the capacitance-component period has not been determined. It was assumed by the above-mentioned authors that the total capacitance of the secondary circuit, including the distributed capacitance of the secondary winding, was completely discharged. Taylor Jones,* however, in describing the spark discharge of induction coils, states that the initial spark (the capacitance component) is probably the discharge of that portion of the total charge which is stored on or near the secondary terminals at the moment when the discharge begins. Taylor Jones† also shows that the discharge may consist of two or three sparks when the primary current is adjusted to the minimum value required to break down the spark-gap, the voltage of the second and third sparks being lower than the voltage of the initial spark. Now it is probable that the induction coil which was used by Taylor Jones was adjusted for optimum secondary potential in accordance with his theory, which implies zero primary potential and zero current in both primary and secondary windings at the moment of maximum secondary potential, the whole of the energy being electrostatic energy in the secondary capacitance. Therefore if all this energy is dissipated in the capacitance component the discharge can only consist of the capacitance component. It would thus appear that only a part of the secondary electrostatic energy is dissipated in the capacitance component, sufficient remaining in the system to produce one or more additional high-voltage sparks.

In a coil ignition system the capacitance of the primary condenser necessary to suppress arcing at the contacts is generally considerably greater than the value required for optimum secondary potential, particularly with an unloaded coil. Therefore the conditions for optimum results do not apply, and at the moment of maximum secondary potential the total energy in the coil system may be considerably greater than the secondary electrostatic energy. The excess energy, in addition to that part of the secondary electrostatic energy which is not dissipated during the period of the capacitance component, therefore remains in the coil system after the capacitance component has ceased. It would appear that a large proportion of this remaining energy is transformed into electromagnetic energy during the oscillation of the inductance component which follows the capacitance component. The inductance component breaks down in the trough of its oscillation, the secondary capacitance is recharged to some potential lower than the initial breakdown voltage of the spark-gap, and a second spark occurs. The process is repeated until the available energy is insufficient to charge the secondary capacitance to the necessary potential, and the discharge ceases in the trough of an oscillation of the inductance component.

It would appear, therefore, that the spark discharge of an ignition coil will generally consist of several high-voltage sparks, even when the breakdown voltage of the gap before the discharge starts is equal to the open-circuit voltage of the coil. Further, in order to maintain regular sparking, some reserve of voltage is necessary to compensate for variations in the spark-gap voltage and in the voltage produced by the coil. It will be shown later in the paper that a reserve of voltage of 10 per cent produced a discharge having a duration of at least 0·83 millisecond as measured by means of a rotary spark-gap. It follows, provided the period of open circuit is small enough, that energy will be transferred to the primary circuit when the contact breaker closes, even when the reserve of voltage is only of the order of 10 per cent or less; the energy transfer is not restricted to the case when the reserve of voltage is large. It is also probable that a similar transfer of energy will occur after the discharge has ceased, providing the contact breaker closes before the decay of energy is complete, that is, before the oscillations which occur in both secondary and primary circuits after the discharge has broken down, have ceased.

(3) OPERATION OF DOUBLE CONTACT-BREAKERS

It is considered that the period of open circuit of a single contact-breaker should not be less than 40 per cent of the total sparking period, since for smaller periods the wear of the fibre heel would be excessive owing to the necessarily small width of heel and highly-sloping cam crests. The high-speed operation would also tend to be irregular owing to "fling," i.e. the heel would not follow the cam surface.

The open-circuit period can be further reduced by the use of two contact breakers, connected in parallel, and disposed at an angle such that one closes the primary circuit soon after the other has broken it. If the second contact-breaker breaks after the first has closed again, the high-voltage spark will occur only on the opening of the first contact-breaker, and the number of cam crests is equivalent to the number of cylinders, each contact breaker operating at the total sparking frequency of the ignition coil.

A better arrangement is to dispose the contact breakers at an angle equivalent to the cylinder displacement, and arrange the open- and closed-circuit angles of each contact breaker such that one closes the circuit and subsequently breaks before the other closes. The number of cam crests is now equal to half the number of cylinders, and each contact breaker operates at half the total sparking frequency of the ignition coil. This arrangement is often used on 6- and 8-cylinder engines when extra-high speeds are required. A similar double contact-breaker system, but with two 6-crest cams disposed at an angle of 30°, was adopted by the Remy Electrical Co., of Anderson, U.S.A., in 1918 for 12-cylinder engines.

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* "Induction Coil Theory and Applications" (Pitman, 1932).

† *Ibid.*

The system employed for the experimental work described in this paper has two parallel-connected contact breakers disposed at 150°, actuated by a 6-crest cam. The static angles of open and closed circuit of each contact breaker are approximately $34\frac{1}{2}°$ and $25\frac{1}{2}°$ respectively for a contact gap of 0·012 in. The combined static angles of open and closed circuit are therefore $4\frac{1}{2}°$ and $25\frac{1}{2}°$ respectively.

(4) DESCRIPTION OF IGNITION UNIT AND APPARATUS

The complete ignition unit comprises an ignition coil, the double contact-breaker, which has tungsten contacts, a condenser connected across the contacts, a 6-crest cam, and a 12-cylinder distributor of the spark-gap type. Fig. 1 shows a view of the double contact-breaker, the condenser, and the distributor rotor, behind which is the cam. The ignition coil is of the modern type described by Watson* and has a straight laminated core with an open magnetic circuit. The secondary winding is wound on the core and the primary winding is wound over the secondary. The whole coil is contained in a metal case having a diameter of $2\frac{1}{4}$ in. and a length of $3\frac{1}{2}$ in.

The distributor was connected to a 12-way spark-gap by means of plain rubber h.t. cables. Each spark-gap consists essentially of two steel balls, $\frac{1}{4}$ in. diameter, one insulated and one earthed, and an insulated pointed electrode of brass. The point is set 0·5 mm. from the surface of the insulated ball and 2 mm. behind the face adjacent to the earthed ball. The insulating material is red fibre which has been impregnated with paraffin wax. The insulation resistance between the balls is of the order of 100 megohms as measured by a 500-volt Megger. Under these conditions a small discharge passes between the point of the brass electrode and the insulated ball, and ionizes the main spark-gap. The spark lag of the main gap is consequently small, and the voltages of successive sparks do not vary to any great extent. The gap can thus be adjusted with considerable accuracy to its limiting length for regular sparking.

The voltage was measured by means of a thermionic peak voltmeter, consisting of a suitable rectifying valve, reservoir condenser, and electrostatic voltmeter. The measurements were carried out with a battery e.m.f. of 11·5 volts and a maximum primary current of 3·1 amperes, since intermittent violent sparking occurred at the contacts if this value of maximum current was exceeded, owing to the rather small pressure between the contacts. The maximum primary current is the current at zero speed with the contacts closed, and is the limiting value of the primary current at break. It was maintained constant at 3·1 amperes by means of a non-inductive resistance in series with the primary winding.

(5) MEASURED SECONDARY-VOLTAGE CHARACTERISTICS

Fig. 2A shows the regular sparking voltages with various loads connected across the measured gap. The regular sparking voltage is the highest voltage, as measured by the peak voltmeter, at which sparking can be maintained regular. The curves are plotted to a base of sparking frequency, and show that the Service specification requirement of 9 000 volts with 250 $\mu\mu$F shunted capacitance can only be obtained up to about 200 sparks per sec., while 5 000 volts with 250 $\mu\mu$F shunted capacitance and 0·2 megohm shunted resistance is just obtained at low speed. The maximum voltage produced by the ignition system with plain cables is also shown. This is the voltage, as measured by the peak voltmeter, with the spark-gap opened so that no spark occurred, i.e. the maximum value of the open-circuit voltage. Intermittent sparking at the contacts at low speeds reduced the regular sparking voltage considerably. The difference between the two curves at high speeds is due mainly to irregularities in the action of the contact breakers.

It was found that, at sparking frequencies in excess of 100–150 per sec., the voltage of the measured gap was influenced by the spark discharge of the previous gap, i.e.

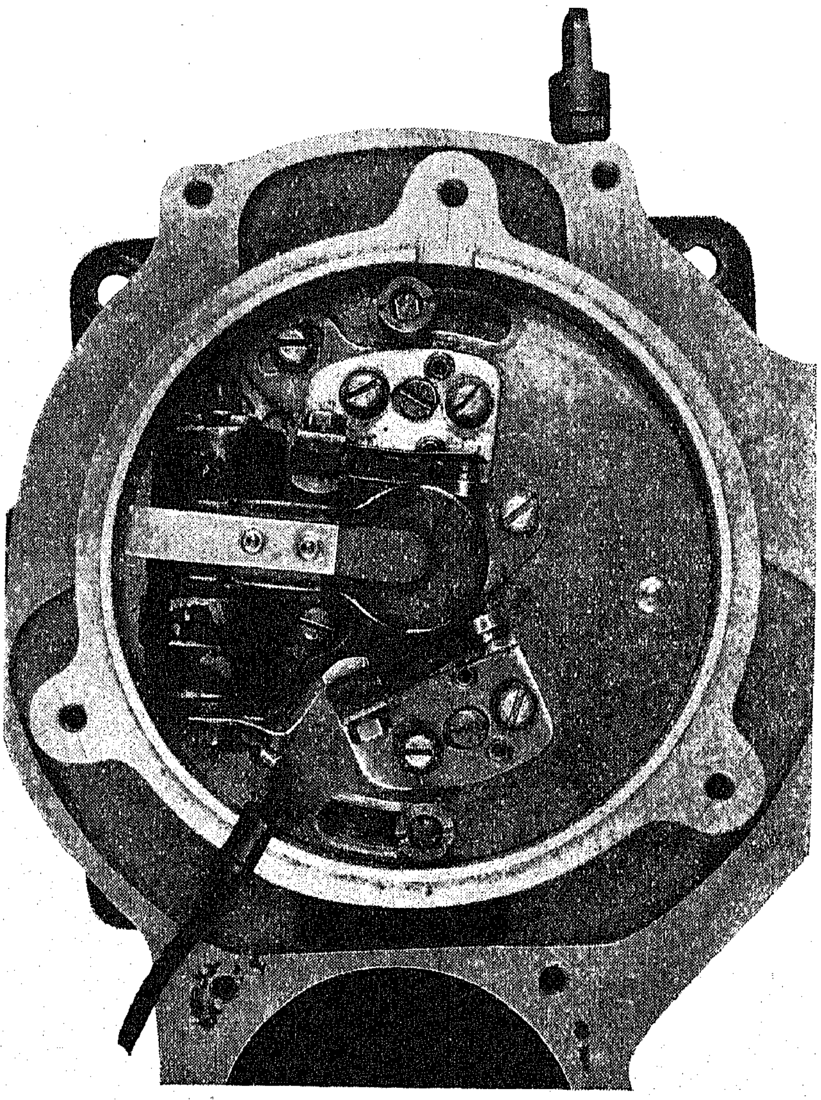

Fig. 1

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* "Coil Ignition Systems," *Journal I.E.E.*, 1932, vol. 70, p. 123.

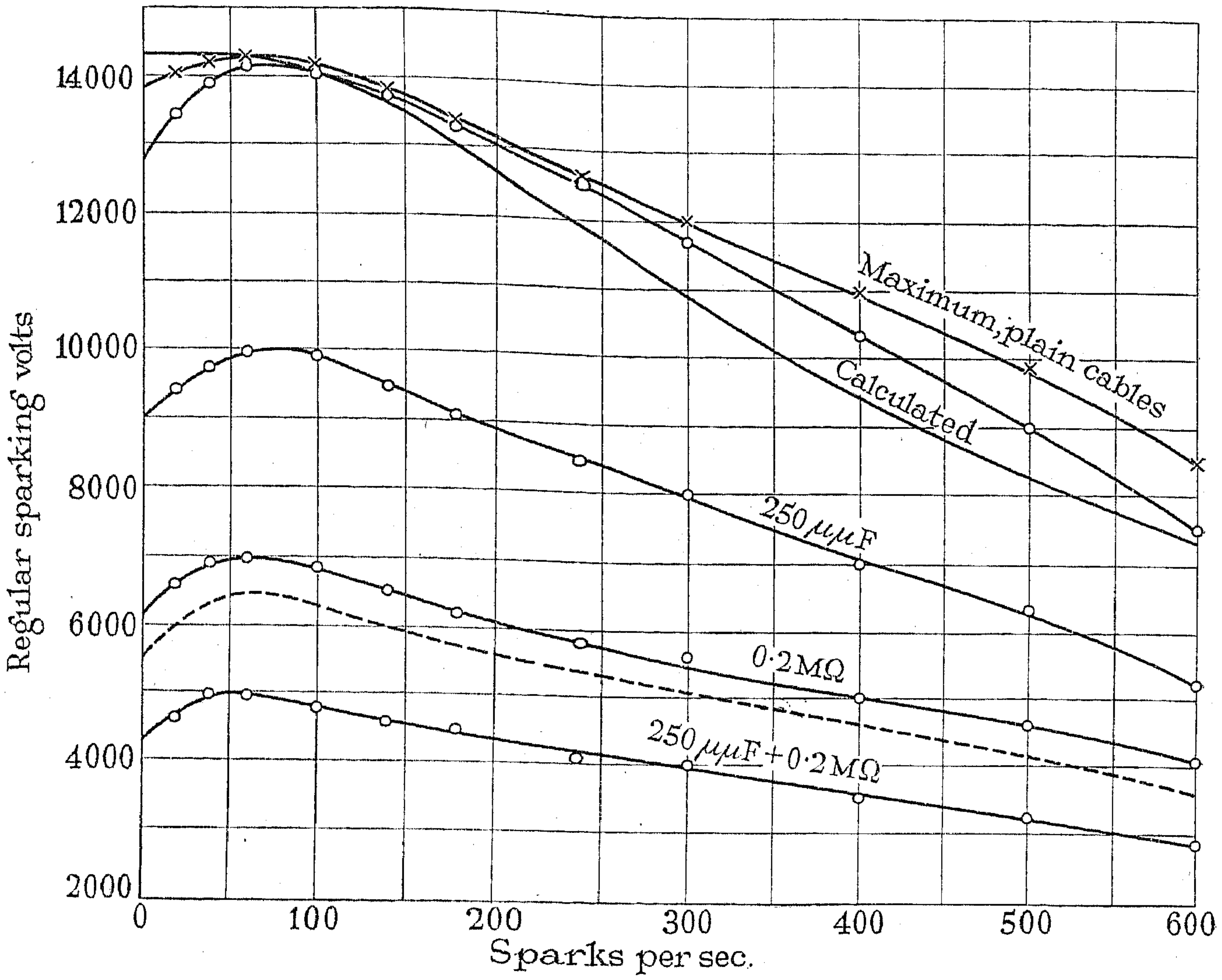

Fig. 2A.—Voltage characteristics of 12-cylinder coil ignition system. Maximum current 3·1 amps., battery e.m.f. 11·5 volts.

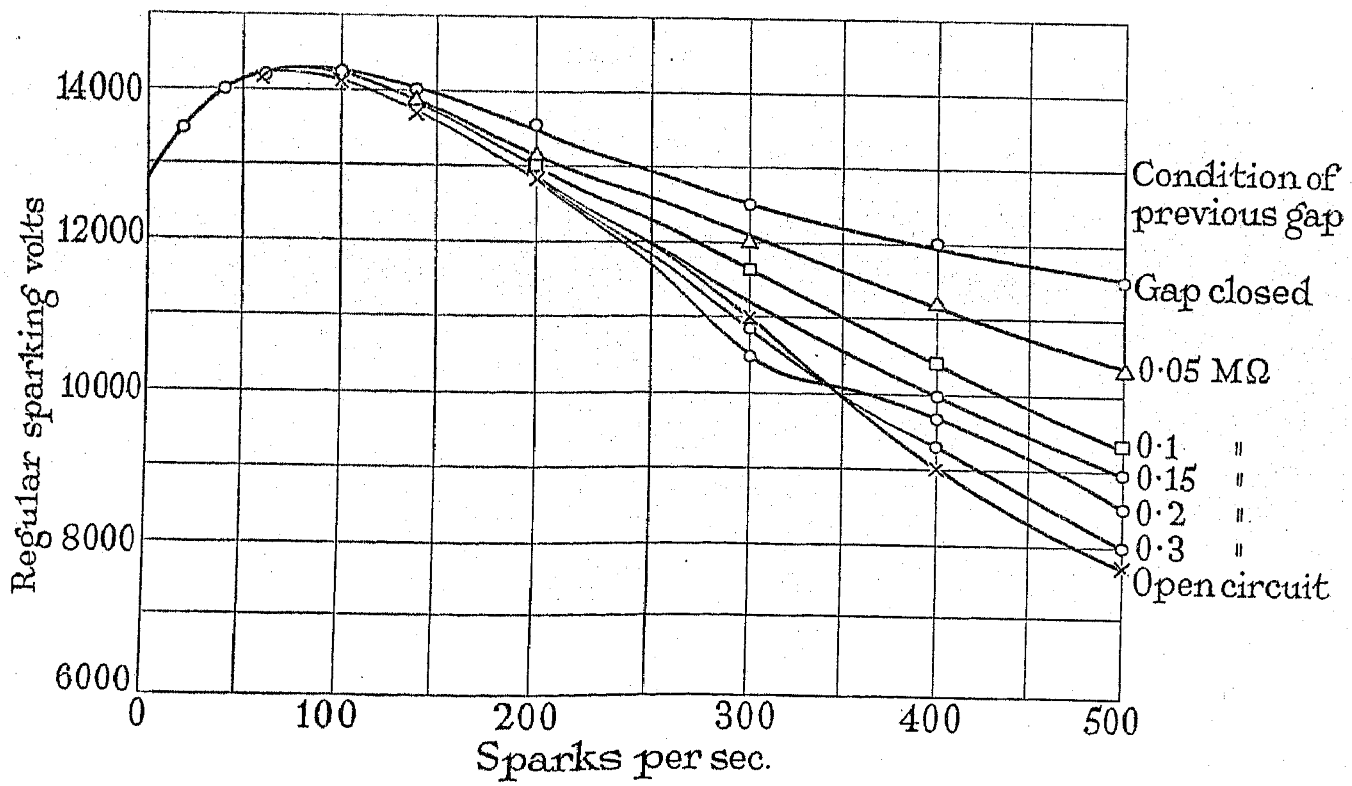

Fig. 2B.—Voltage characteristics with shunted resistance across previous non-sparking gap.

by the gap immediately preceding the measured one. The voltage of the measured gap increased considerably as the voltage of the previous gap was decreased from its open-circuit value to zero by decreasing the length of the gap. The regular-sparking-voltage readings shown in Fig. 2A were obtained with all 12 gaps set for just-regular-sparking at all speeds. This is the practical condition for the measurement of the secondary voltage of a magneto or an ignition coil, particularly at high speeds, since the measured voltage then represents the highest value at which regular sparking can be maintained on all the spark-gaps.

(6) MEASUREMENT OF THE EFFECT OF THE SPARK DISCHARGE

The regular sparking voltage on one spark-gap was measured for various values of shunted resistance across the previous gap, which, except for the closed-circuit readings, was opened sufficiently far for no sparking to occur. Fig. 2B shows the results, and it can be seen that the highest voltage is obtained with the previous gap closed. In general, the measured voltage is lowest when the previous gap is open-circuited, but the values for 0·2 and 0·3 megohm are slightly lower over a small frequency range.

Fig. 3A shows the results plotted to a base of shunted resistance for various sparking frequencies. These curves show that the voltage generally decreases with increase of resistance across the previous gap.

The broken-line curve in Fig. 3A shows the results obtained at 400 sparks per sec. by varying the shunted resistance across the previous gap, when this gap was set at 6 000 volts (peak). The voltage of the measured gap decreases slightly as the resistance across the previous gap is decreased from 0·5 to 0·25 megohm, the latter being the limiting resistance below which regular sparking was not maintained at the previous gap. Further decrease of the resistance causes a rapid fall in the voltage of the measured gap until sparking ceases at the previous gap at 0·2 megohm, below which resistance the measured voltage rises again along the full-line curve for 400 sparks per sec. The increase in performance represented by the difference between the broken-line curve and the full-line curve for 400 sparks per sec. is due to the persistence of the spark discharge of the previous gap. The two curves show clearly how the available voltage at one sparking plug may be altered by the insulation resistance of the previous plug.

The regular sparking voltage was measured with various capacitance loads on the previous gap, both when the previous gap was set at 6 000 volts and when it was opened so that no sparking occurred. Fig. 3B shows that in the former case the voltage at the measured gap decreases considerably with increase of shunted capacitance. In the latter case there is a small decrease in the measured voltage as the capacitance increases from zero to 100 $\mu\mu$F. This would appear to substantiate the view already stated that energy may be re-transferred to the primary circuit after the discharge has ceased (or, as in the present case, with no discharge) providing the decay of energy in the coil system is not complete before the contact breaker closes.

Fig. 3C shows the effect of varying the sparking voltage of the previous unloaded gap. The measured voltage increases considerably as the previous-gap voltage is decreased. The limit of regular sparking of the previous gap is 11 200 volts, compared with 10 300 volts on the measured gap, owing to the fact that the remaining 10 gaps were all sparking at 6 000 volts.

The broken-line parts of the curves of Figs. 3B and 3C indicate the unstable conditions between no sparking and just-regular-sparking on the previous gap. Fig. 3C shows that the regular-sparking voltage decreases quickly when the previous spark becomes irregular, while the maximum voltage falls more slowly to the sparkless limit.

It should be noted that, if one gap ceases sparking owing to insufficient voltage not caused by a low value of shunted resistance such as a breakdown in the insulation of a sparking plug, but arising from, say, a large spark-gap caused by electrode erosion, the following gap will spark irregularly. It was found during the tests, by adjusting all 12 gaps to the just-regular-sparking limit and then opening one, that in consequence as many as the 3 following gaps sparked irregularly.

(7) GENERAL DEDUCTIONS FROM THE CURVES

A comparision of Fig. 3C with the full-line curve for 400 sparks per sec. of Fig. 3A shows that the effect of a resistance of 0·1 megohm connected across the previous non-sparking gap is approximately equivalent to the effect of a just-regularly-sparking gap of 11 200 volts, the measured voltage being 10 300 volts in both cases. Reducing the voltage of the previous gap to 6 000 volts is equivalent to reducing the shunted resistance to 0·05 megohm, the voltage at the measured gap now being 11 200 volts. Fig. 3C also shows that the voltage at the measured gap decreases regularly as the voltage of the previous gap is increased from zero to the limit for regular sparking of 11 200 volts. Now it has been shown that the nature of the spark discharge changes from a low-voltage pulsating arc to a series of high-potential sparks as the breakdown voltage of the gap is increased from a low value to a value comparable with the output voltage which the coil can deliver. Thus, since there is no abrupt change in the slope of the curves of Fig. 3C from zero to 11 200 volts at the previous gap, the change in the characteristics of the spark discharge does not abruptly alter the amount of energy which is re-transferred to the primary circuit. It is only when the previous gap commences to spark irregularly that the voltage of the measured gap decreases quickly. Thus, providing the sparking is regular, the coil acts as if the secondary winding is shunted by a resistance of low ohmic value as compared with the mimimum specified resistance of a leaky sparking-plug—0·2 megohm. For a given period of open circuit, which in the present case at 400 sparks per sec. is approximately 0·4 millisec., the energy transferred to the primary circuit increases as the gap voltage is decreased, since there is less loss of energy while the secondary capacitance is being charged to the sparking voltage and the total duration of the discharge is increased. A similar effect is obtained by a decrease in the capacitance with a constant gap voltage—Fig. 3B—and for the same reasons.

The approximate increase in performance which is obtained by the closing of the primary circuit before the

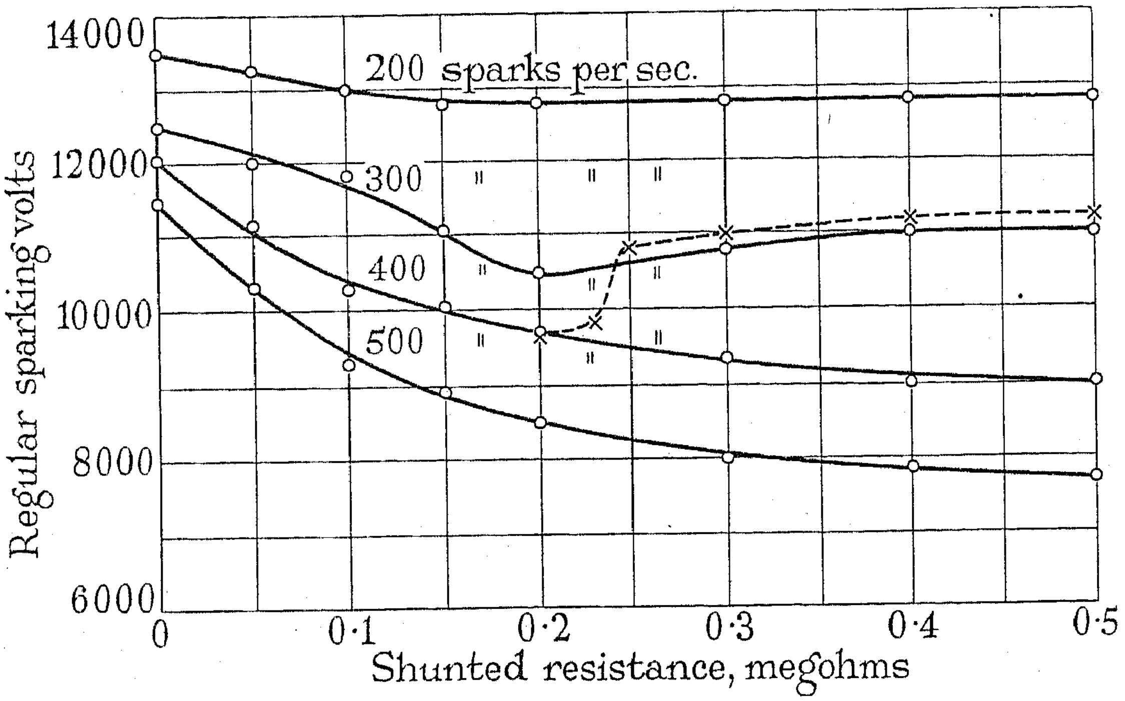

Fig. 3A.—Variation of voltage with resistance shunted across previous non-sparking gap.

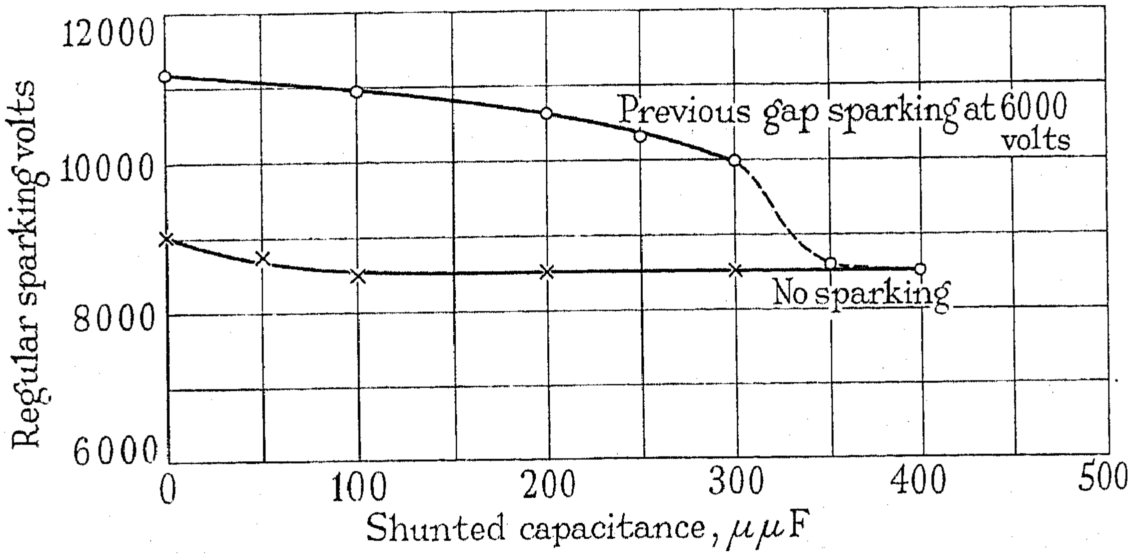

Fig. 3B.—Variation of voltage at 400 sparks per sec. with capacitance shunted across previous gap.

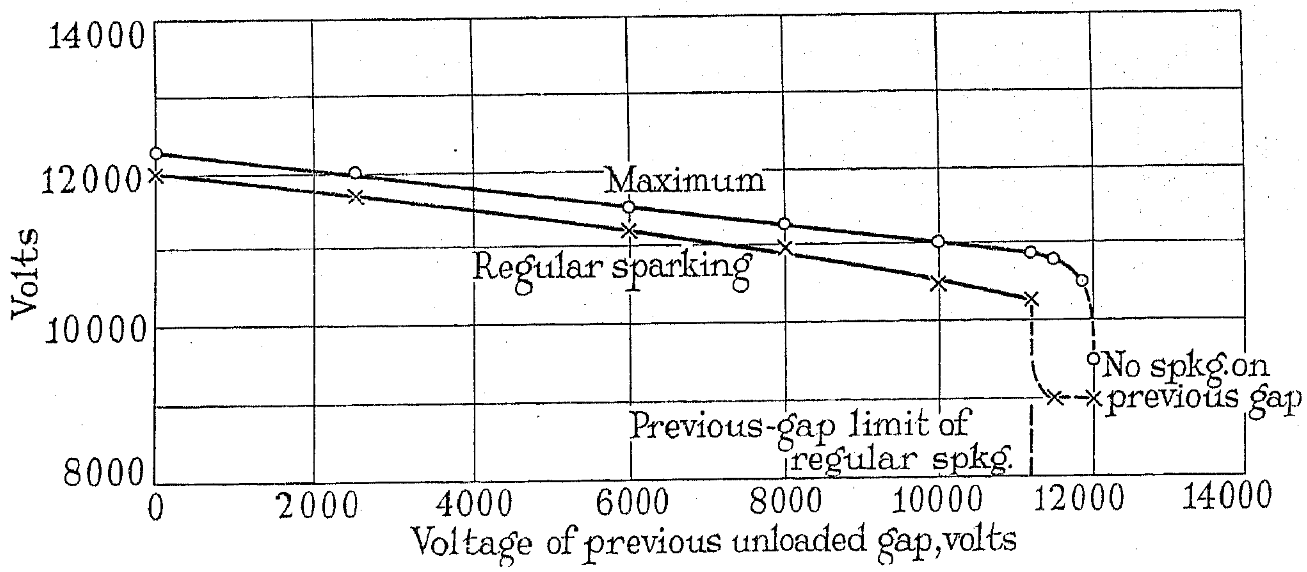

Fig. 3C.—Variation of voltage at 400 sparks per sec. with voltage of previous unloaded gap.

spark discharge ceases will be estimated from the voltage-increases shown in Figs. 3A, 3B, and 3C. Now the measured output with plain cables at 400 sparks per sec., with all spark-gaps set for just regular sparking, is 10 300 volts (Fig. 2A). This value is also shown in Fig. 3C with the previous gap set at its limiting voltage for regular sparking, whereas with no sparking at the previous gap the measured voltage is only 9 000 volts. Therefore the effect of the persistence of the spark discharge is to increase the measured voltage from 9 000 to 10 300 volts, an increase of 14·5 per cent. The corresponding measured voltages in Fig. 3A are 9 600 and 10 800 volts, an increase of 12·5 per cent, and in Fig. 3B are 8 500 and 10 000 volts, an increase of 17·6 per cent. A single measurement at 400 sparks per sec. with the Service specification loading of 250 $\mu\mu$F plus 0·2 megohm shunted across the previous gap, which was set at its regularly-sparking limit, showed 8 800 and 10 000 volts, an increase of 13·6 per cent. Thus for all normal loads, i.e. a shunted resistance as low as 0·2 megohm and a shunted capacitance up to 300 $\mu\mu$F, or a combination of these loads, the measured voltage-increase only varies from 12·5 per cent to 17·6 per cent provided the previous gap is set at its limiting voltage for regular sparking corresponding to the particular load. The increase in the regular sparking output, due to the effect of the persistence of the spark discharge, is therefore approximately independent of secondary loading due to normal values of shunted capacitance and/or resistance, and an assumed average increase of about 15 per cent will be satisfactory for the present purpose. The maximum-voltage curve of Fig. 3C shows an increase of 14·7 per cent (9 500 to 10 900 volts) and will therefore be considered, since measured maximum voltages should be directly comparable with calculated values. The increase in performance which was obtained by a decrease in the shunted capacitance across the previous non-sparking gap from 100 $\mu\mu$F to zero (Fig. 3B) will be neglected.

(8) DURATION OF SPARK DISCHARGE, AND ANGLE OF OPEN CIRCUIT

The duration of the spark discharge was measured by means of a rotary spark-gap set at 10 000 volts (peak) with an available open-circuit coil voltage of 11 000 volts, conditions corresponding approximately to the regular-sparking limiting conditions of Fig. 3C. It was found that if the coil output was reduced below 11 000 volts sparking tended to become irregular, and no accurate measurement of the discharge duration could be made. The distributor speed was 500 r.p.m., corresponding to a sparking frequency of 100 per sec. Regular spark discharge occurred over an arc of 2½°, corresponding to a discharge duration of 0·83 millisec., but irregular sparks appeared up to 4°, showing that energy remained in the coil system for at least 1·33 millisec. after the first spark. The approximate period between the instant of break and the first spark was deduced from spark-position/speed readings and had a value of 0·078 millisec. The total period from the instant of break was therefore approximately 1·4 millisec., the period for regular discharge being 0·9 millisec.

The angle of spark discharge remained approximately constant at 4½° from 110 to 420 sparks per sec., but was erratic above the latter frequency, and at 500 sparks per sec. had increased to 6°. The total angle of open circuit increased from 4½° (measured statically) to about 5·3° at 400 sparks per sec. The angle of discharge was measured for all 12 distributor leads and found to vary between 4° and 4½° at 400 sparks per sec. The closed- and open-circuit angles will therefore be taken as 25° and 5° respectively, with corresponding closed- and open-circuit periods at 400 sparks per sec. of 2·08 and 0·42 millisec. respectively.

It should be noted that the rotary spark-gap which was used for the measurements is of the type in which the earth electrode rotates with the h.t. electrode. The position of the spark on the scale, which has a diameter of 11 in., can thus be accurately measured, since the spark is not deflected as in the type where the spark passes between a rotating electrode and a stationary metal ring.

The period necessary for the total decay of energy in the coil system was also deduced from the minimum speed at which a difference in the coil voltage could be detected with and without the spark discharge. The primary winding of the coil was connected directly across a 6-volt battery in order to obtain a more rapid fall of secondary voltage with speed, and the h.t. leads were connected across the ball gaps. The difference in output was detected by setting several of the ball gaps to the regular sparking limit and then opening one, when the following gap sparked irregularly if the sparking frequency was sufficiently high. A difference could be detected as low as 130 sparks per sec., corresponding to an open-circuit period of approximately 1·2 millisec. Thus, although regular discharge on the rotary spark-gap ceases 0·9 millisec. after break, sufficient energy is re-transferred to the primary circuit after 1·2 millisec. to produce a small increase in the coil output. Therefore the energy cannot be completely dissipated, and it will be assumed that the total period for the complete decay to zero is 1·4 millisec. after the opening of the contact breaker, i.e. energy will be re-transferred to the primary circuit if the period of open circuit is less than 1·4 millisec.

(9) COIL CONSTANTS

The constants of the ignition coil are as follows:—

Primary inductance	= 7·17 millihenrys
Secondary inductance ..	= 34·9 henrys
Mutual inductance	= 0·468 henry
Coil coupling	= 0·875
Primary d.c. resistance ..	= 2·0 ohms at 13° C.
Secondary d.c. resistance ..	= 4 180 ohms at 13° C.
Primary-condenser capacitance	= 0·222 μF

The primary and secondary inductances, and the primary condenser capacitance, were measured by an a.c. bridge at 1 000 cycles per sec. The mutual inductance was measured by a Grassot fluxmeter connected across the primary winding for a range of secondary current from 1·0 to 10·0 milliamps., which corresponds approximately to a range of primary current from 0·07 to 0·7 ampere, and was found to be substantially constant. The maximum divergence from the mean value of 0·468 henry was 2 per cent, and there was no definite increase or decrease with increase of current. It will therefore be assumed that the inductances of this short, straight-cored coil with an open magnetic circuit are constant up to the maximum primary current of 3·1 amperes. The coil coupling—0·875—has been calculated from the mean value of the mutual inductance, and the bridge values of primary and secondary inductances.

(10) EFFECT OF VARIATION OF PERIOD OF OPEN CIRCUIT UPON GROWTH OF PRIMARY CURRENT AT 400 SPARKS PER SECOND

Curve A of Fig. 4A shows the primary-current/time curve calculated from the equation

$$I = I_0(1 - e^{-Rt/L}) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where I_0 = maximum primary current (= 3·1 amperes), t = period of closed circuit (sec.), L = primary inductance = 0·00717 henry, and R = resistance of primary circuit (= 3·71 ohms for a battery e.m.f. of 11·5 volts).

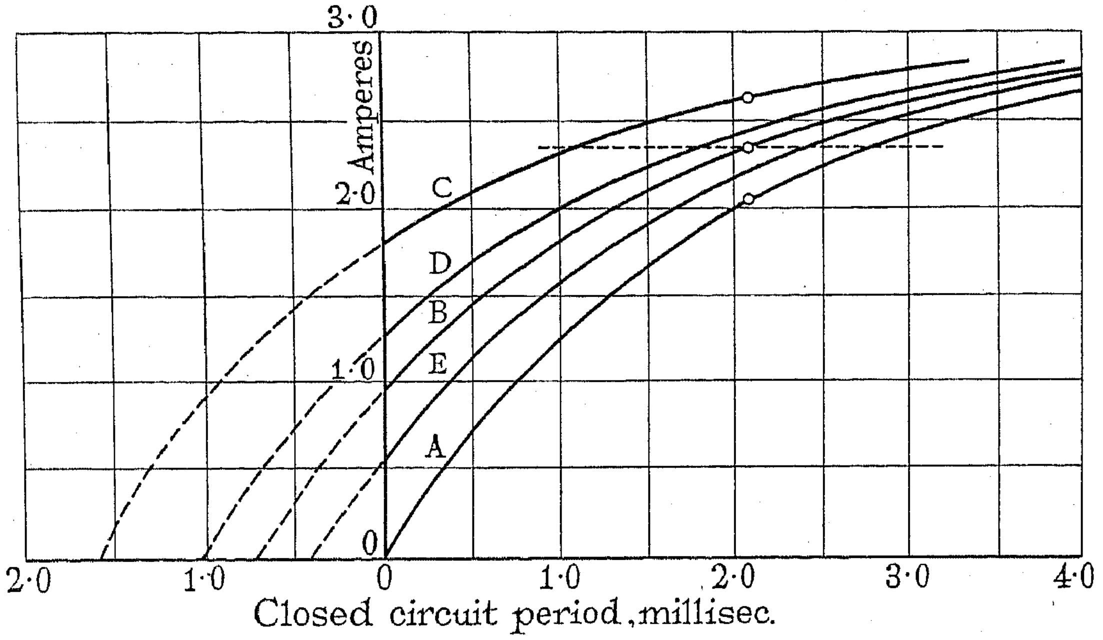

Fig. 4A.—Estimated primary-current curves showing effect of variation of period of open circuit: based on measured secondary voltages.

Fig. 2A shows that a maximum secondary voltage of 14 300 volts is obtained with a primary break current of 3·1 amperes. Now secondary voltage is proportional to primary break current if the inductances and effective resistances of the coil are constant over the range of current which is being considered. On this assumption the primary currents corresponding to the maximum voltages shown in Fig. 3C are as follows: Previous gap short-circuited (12 200 volts), 2·65 amperes; previous gap just-regular sparking (10 900 volts), 2·36 amperes; no sparking on previous gap (9 500 volts), 2·06 amperes.

These values of primary current are plotted in Fig. 4A for the measured period of closed circuit, at 400 sparks per sec., of 2·08 millisec., and it can be seen that the value of 2·06 amperes almost coincides with the calculated curve A. This close agreement constitutes a check on the primary inductance as measured by the a.c. bridge, and it shows that the assumption that the inductances and effective resistances of the coil are approximately constant up to a primary current of 3·1 amperes is justified. It should be noted that the voltage across the distributor gap has been neglected in the estimation of primary break currents. The error involved is, however, negligible, since the coil voltage only exceeded the spark-gap voltage by 300 volts over the frequency range 50–400 sparks per sec.

The periods necessary for the primary current to rise to 2·36 and 2·65 amperes respectively with no effect from the previous discharge can be calculated from equation (1) and are 2·77 and 3·73 millisec. respectively. The complete curves are shown in Fig. 4A (curves B and C), drawn parallel to curve A from negative periods of 0·69 and 1·65 millisec. respectively. This method neglects the small period of 0·01 to 0·1 millisec. during which energy is transferred from the secondary to the primary.

The increase in primary current shown by curves B and C represents the effect of the persistence of the spark discharge with an open-circuit period of 0·42 millisec. The average value of curve B is 1·75 amperes, corresponding to 1·46 amperes during the total period of 2·5 millisec. The measured current at 400 sparks per sec. with all 12 gaps just regularly sparking was 1·5 amperes, which is within 3 per cent of the calculated value. It was verified during the tests that the current decreased considerably when the spark-gaps were opened so that no sparking occurred, and increased considerably when the spark-gaps were closed. The actual values of current were not measured.

The current at the instant of make in curve B, which represents the energy transferred to the primary circuit when all the spark-gaps were set to the limiting voltage for regular sparking, is 0·93 ampere. In order to estimate the effect of the variation of the period of open circuit upon the growth of primary current, the variation of curve B with the period of open circuit must be estimated. Now it has been shown that, although the spark discharge generally breaks down 0·9 millisec. after the opening of the contact breaker, the period necessary for the complete decay of the energy in the coil system is approximately 1·4 millisec. Further, it has also been shown that the average value of the unidirectional secondary current decays according to a straight-line law until the discharge breaks down. Therefore for the present purpose it will be assumed that the average value of the secondary current follows a straight-line law of decay to zero in 1·4 millisec. after the opening of the contact breaker. Since the make current is proportional to the average value of the secondary current at the instant the contact breaker closes, the approximate make current, corresponding to a break current of 2·36 amperes, is given by

$$I_m = 0{\cdot}93\left(\frac{1{\cdot}4 - t'}{1{\cdot}4 - 0{\cdot}42}\right)$$

where t' is any open-circuit period less than 1·4 millisec. The apparent period necessary for the current to rise to the value I_m can be calculated from equation (1) and the complete curve drawn.

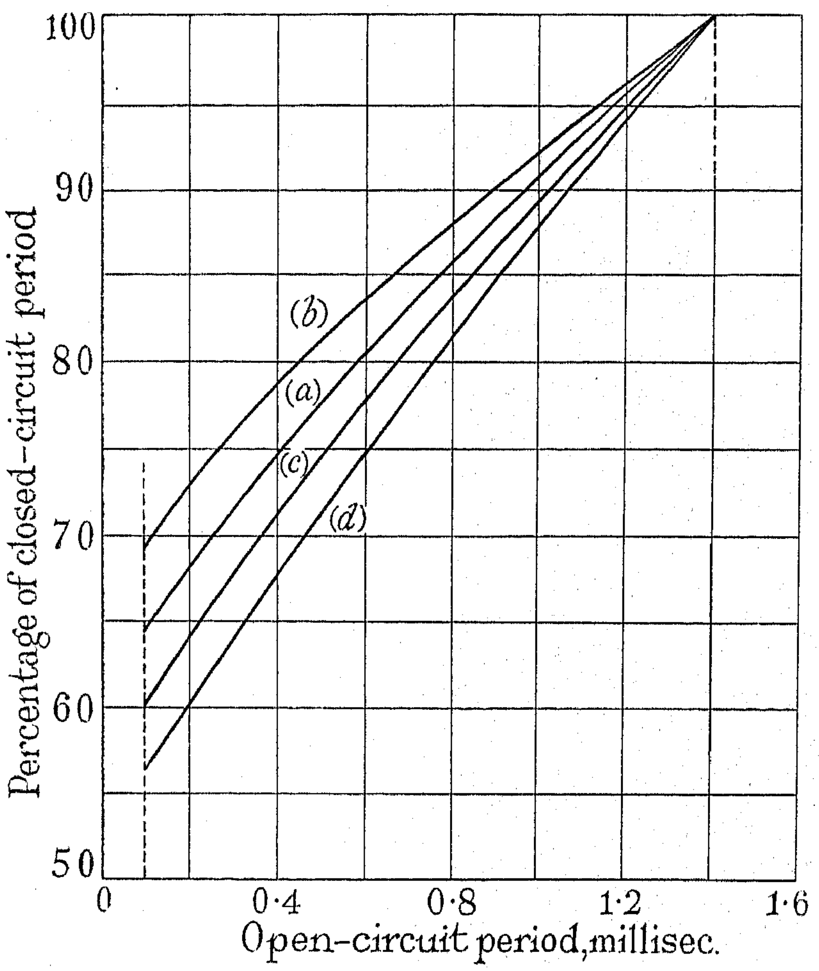

Fig. 4B.—Estimated variation of closed-circuit period for various values of break current: based on measured secondary voltages.

Curve (a): $I = 0{\cdot}76\, I_0$
Curve (b): $I = 0{\cdot}85\, I_0$
Curve (c): $I = 0{\cdot}65\, I_0$
Curve (d): $I = 0{\cdot}5\, I_0$

Curves D and E show current/time curves for open-circuit periods of 0·1 and 0·84 millisec. respectively. Curve D represents the maximum increase which can be obtained, taking 0·1 millisec. as the lower limit of the period of open circuit, this value being slightly greater than the approximate period of 0·078 millisec. to the first spark which was deduced from spark-position/speed readings, and the value usually assumed.

The effect of the variation of the period of open circuit can be estimated from the variation in the period of closed circuit necessary for the primary current to build up to 2·36 amperes. The periods for 1·4, 0·84, 0·42, and 0·1 millisec. are 2·77, 2·4, 2·08, and 1·77 millisec. respectively. Curve (*a*) of Fig. 4B shows the closed-circuit period as a percentage of the calculated period of 2·77 millisec. between the open-circuit period limits of 0·1 and 1·4 millisec., plotted from the above figures. This curve applies to a break current which is 76 per cent of the maximum current.

It is apparent that the effect of a given open-circuit period will depend upon the ratio of break current to maximum current, and curves similar to curve (*a*) are shown for various other values of break current in Fig. 4B. The curves are calculated from the following equation, which can be deduced from equation (1):—

$$1 - \frac{t_m}{t} = 1 - \frac{\log\left[I_0/(I_0 - I_m)\right]}{\log\left[I_0/(I_0 - I)\right]}$$

where t_m is the calculated period necessary for the current to build up to the value I_m occurring at the instant of make. The curves show that the period of closed circuit is reduced as the break current is reduced in proportion to the maximum current.

(11) APPLICATION OF THE CURVES

The curves of Fig. 4B can be used to determine the diminution of the period of closed circuit necessary to produce any given amount of primary energy at break, on the assumption that the make current is a fixed proportion of the break current for a given period of open circuit. That this assumption is approximately correct is shown by the following consideration of the energy in the coil system between break and make.

It has been shown that the secondary voltage is approximately proportional to the primary break current. Therefore the energy in the coil system at the instant the first spark occurs is approximately proportional to the initial primary energy, which is proportional to the square of the primary break current. The energy lost during the capacitance-component period is approximately proportional to the square of the sparking voltage, and therefore to the square of the primary break current, since the capacitance which discharges is independent of the magnitude of the break current. Thus the energy which remains in the coil system after the capacitance component has ceased is approximately proportional to the initial primary energy. This energy takes the form of electromagnetic energy in the secondary winding due to the oscillation of the inductance component which follows the capacitance component. Thus the average value of the unidirectional secondary current during this first oscillation is approximately proportional to the primary break current. Now it has been shown that the amount of energy which is re-transferred to the primary circuit is approximately independent of secondary loading due to normal values of shunted resistance and/or capacitance, provided the spark-gap is set at its limiting voltage for regular sparking. The actual gap voltage, however, varies considerably, and it may be deduced that the rate of decay of the discharge current is approximately independent of gap voltage, and therefore of primary break current, provided the gap is set at its

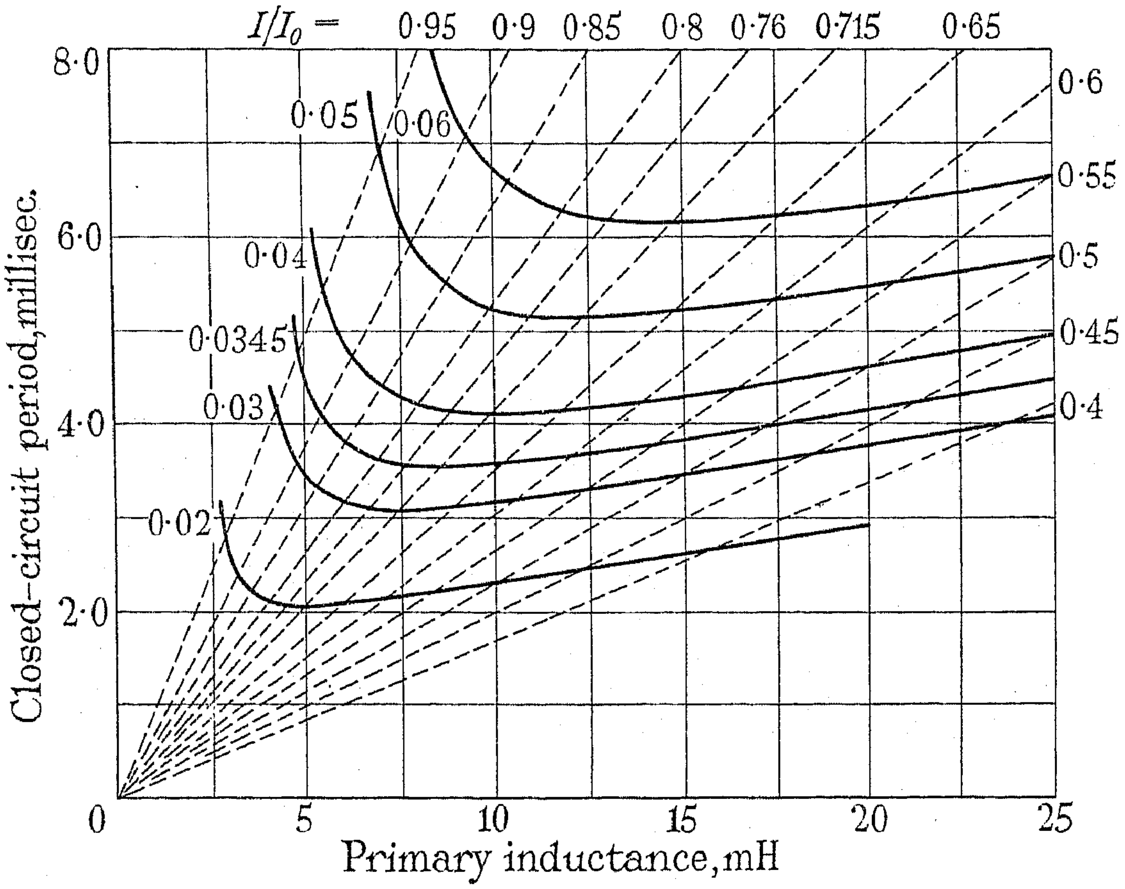

Fig. 5A.—Calculated variation of closed-circuit period with primary inductance for various values of primary energy. Primary volts = 12. Maximum current = 4 amps.

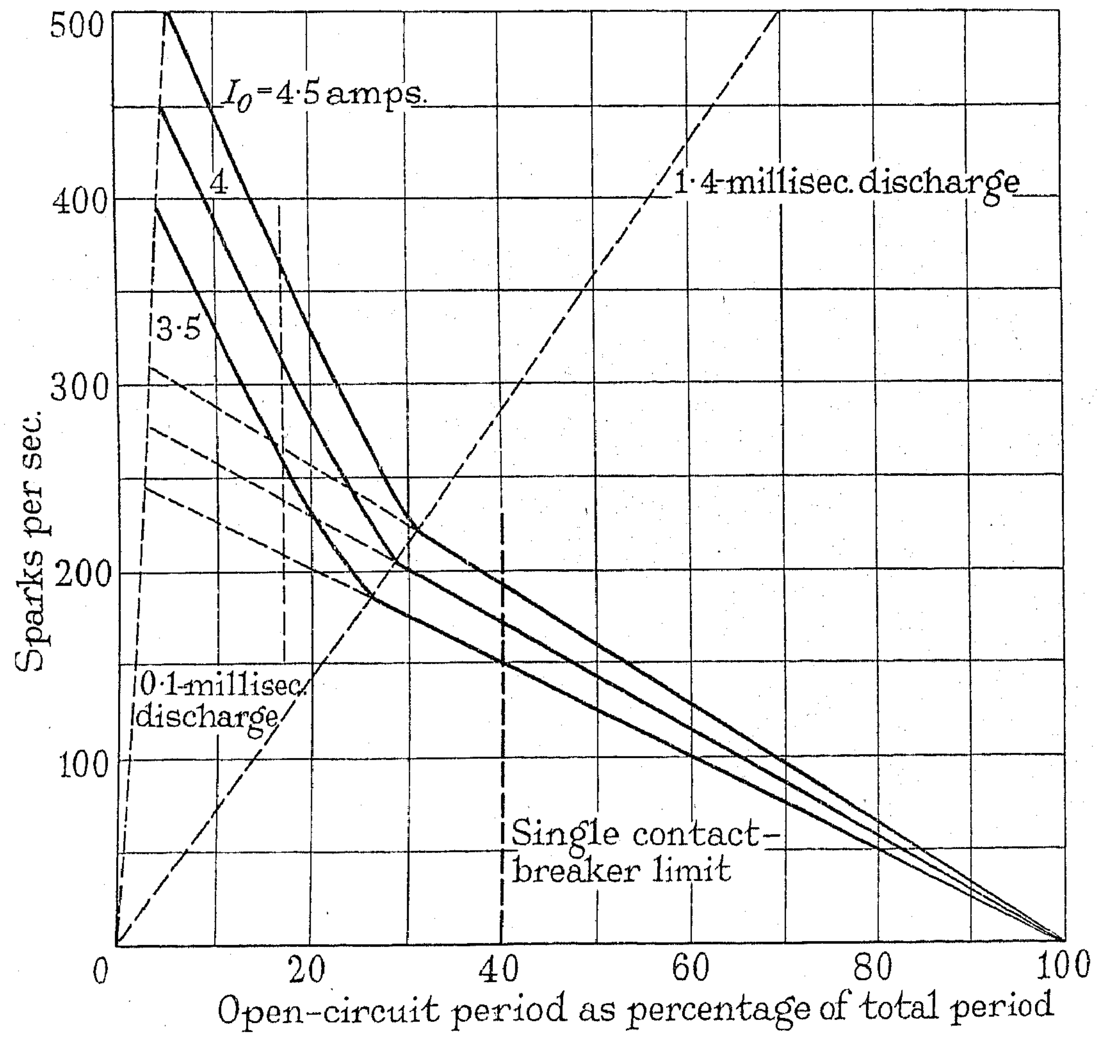

Fig. 5B.—Calculated maximum sparking frequency of 12-volt coil systems for various values maximum current. Output, 5 000 volts. Load, 250 $\mu\mu F + 0 \cdot 2\ M\Omega$.

regular sparking limit. Thus the average value of the unidirectional secondary current is approximately proportional to the primary break current after a given period of open circuit. Since the primary make current is proportional to the average value of the secondary current at the instant of make, the make current is approximately proportional to the break current for a given period of open circuit.

Since the experimental results were obtained on a modern coil it is considered that the losses and coupling may be taken as representative of modern practice. The curves of Fig. 4B, and the performance curves of Fig. 2A, will therefore be generally applied to calculate the maximum sparking frequency of 12-volt coil ignition systems capable of meeting the Service specification requirement of 5 000 volts with 250 $\mu\mu$F shunted capacitance plus 0·2 megohm shunted resistance. The frequency will be calculated for various open-circuit periods for maximum primary currents of 3·5, 4·0, and 4·5 amperes.

Fig. 2A shows that the output of 5 000 volts is just obtained at low speeds, i.e. with a current of 3·1 amperes, corresponding to 0·0345 joule primary energy at the instant of break. It is necessary first to determine the minimum closed-circuit period during which this amount of primary energy can be stored, on the assumption that the energy in the coil system has been completely dissipated before the contact breaker closes. The curves of Fig. 4B can then be applied to calculate the actual closed-circuit period for any given open-circuit period.

(12) CALCULATED MINIMUM PERIOD OF CLOSED CIRCUIT

The primary energy is given by

$$W = \tfrac{1}{2}LI^2 = \tfrac{1}{2}LI_0^2(1 - e^{-Rt/L})^2 \quad . \quad . \quad (2)$$

$$\therefore\ t = \frac{L}{R}\log_e \frac{I_0}{I_0 - \sqrt{(2W/L)}} \quad . \quad . \quad . \quad (3)$$

The curves of Fig. 5A show the variation of the closed-circuit period with primary inductance for various values of primary energy, calculated from equation (3) for a 12-volt system having a maximum current of 4 amperes. The minimum value of L is obtained when $I = I_0$ and t is infinite, and is given by $L = 2W/I_0^2$. As L increases, t rapidly decreases to its minimum value and then increases slowly with further increase of L.

The broken straight lines of Fig. 5A are calculated from the equation

$$t = \frac{L}{R}\left(\log_e \frac{I_0}{I_0 - I}\right)$$

and show the relation between t and L for various values of I/I_0. The points of intersection of the straight lines and the curves show values of L and t for given values of W and I/I_0. It will be seen that the straight line for the case when $I/I_0 = 0{\cdot}715$ passes through the minima of the curves.

It has been shown by E. A. Watson* that the relation between the primary inductance and primary resistance for maximum energy-storage in a given period of closed circuit is given by the equation $t = 1{\cdot}256L/R$. When this holds, $I/I_0 = 0{\cdot}7152$, and the minimum value of t for any given values of W, I_0, and the battery e.m.f. E, can be found as follows:—

$$t_{min.} = 1{\cdot}256\ \frac{L}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$= \frac{1{\cdot}256}{R} \cdot \frac{2W}{I^2}, \text{ from equation (2)}$$

$$= \frac{1{\cdot}256}{R} \cdot \frac{2W}{(0{\cdot}7152I_0)^2}$$

$$= 4{\cdot}91\ \frac{W}{I_0^2R}$$

$$= 4{\cdot}91\ \frac{W}{EI_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Equation (5) shows that the minimum period of closed circuit for a given amount of primary energy (W) is inversely proportional to the maximum power in the primary circuit. Thus the minimum period of closed circuit of a 12-volt system is approximately half that of a 6-volt system, since the limiting value of I_0 is fixed by sparking at the contacts, and is approximately independent of E and L provided the primary condenser has a suitable value.

For given values of W, E, and I_0, the minimum closed-circuit period can be calculated from equation (5), and the best value of primary inductance from equation (4).

(13) CALCULATED MAXIMUM SPARKING FREQUENCY

Equations (4) and (5) apply to the case when the energy in the coil system has been completely dissipated before the contact breaker closes, i.e. to open-circuit periods in excess of 1·4 millisec. It must now be determined whether the condition for the minimum period of closed circuit ($I = 0{\cdot}715I_0$) holds when the period of open circuit is less than 1·4 millisec. The calculation of the necessary period of closed circuit for a primary energy of 0·05W with an open-circuit period of 0·1 millisec. is shown in Table 1 for various values of I/I_0. This table shows that the condition for the minimum period of closed circuit is approximately $I = 0{\cdot}6I_0$. Further, the variation in the actual necessary period of closed circuit is less than 3 per cent from $I = 0{\cdot}715I_0$ to $I = 0{\cdot}55I_0$, since as the period increases in Fig. 5A the percentage given by Fig. 4B decreases. It can be similarly shown that the variation is small for any period of open circuit between 1·4 and 0·1 millisec., and as the open-circuit period decreases the break current for the minimum period of closed circuit decreases from $I = 0{\cdot}715I_0$ to $I = 0{\cdot}6I_0$. For an open-circuit period of 0·53 millisec., which, as will be shown subsequently, is the period corresponding to the calculated maximum sparking frequency, the minimum period of closed circuit is obtained when $I = 0{\cdot}65I_0$ approximately. Thus a sufficiently accurate estimate of the minimum period of closed circuit can be made from equation (5) and curve C of Fig. 4B for the case when $I = 0{\cdot}65I_0$.

Table 2 shows the calculation of the variation of the maximum sparking frequency with the open-circuit period for a 12-volt system having a maximum current of 4 amperes and the primary energy of 0·0345 joule necessary to meet Service specification requirements.

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* *Loc. cit.*

The fourth and fifth columns of the table show the sparking frequency on the assumption that the energy in the coil system is completely dissipated before the contact breaker closes. Comparing frequencies with similar open-circuit periods, it will be seen that the increase due to the persistence of the spark discharge is 63 per cent for 0·1 millisec. open-circuit period, and 35 per cent for 0·4 millisec.

Table 1

I/I_0 .. .. =	0·85	0·76	0·715	0·65	0·6	0·55	0·5
Closed-circuit milliseconds (from Fig. 4A) ..	5·46	5·14	5·12	5·2	5·31	5·51	5·78
Percentage (from Fig. 3B)	69	64·2	62·6	60·2	58·6	57·3	56·1
Actual closed-circuit milliseconds	3·77	3·3	3·2	3·14	3·12	3·16	3·24

Fig. 5B shows the calculated variation of the maximum sparking frequency with the period of open circuit, for maximum primary currents of 3·5, 4·0, and 4·5 amperes. The open-circuit period is expressed as a percentage of the total period, and it is apparent that, with no effect due to the persistence of the spark discharge, the frequency is inversely proportional to the open-circuit period, becoming zero at 100 per cent. The difference between the broken parts of the straight lines and the curves, between the limits of 1·4 and 0·1 millisec., is the increase in sparking frequency due to the persistence of the spark discharge. Considering the period of 16·7 per cent, which corresponds to 5° for a 12-cylinder engine, and is the angle of open circuit in the system employed by the author, the increases are approximately 210 to 260, 240 to 315, and 265 to 365 sparks per sec. These may be compared with the increases shown in Fig. 2A, by the difference between the maximum-voltage and calculated curves, which are approximately 210 to 250, 240 to 300, and 265 to 350 sparks per sec. The increases are less in Fig. 2A, since the break currents are greater than $0{\cdot}65I_0$, but show fairly close agreement with Fig. 5B.

Table 2

Open-circuit milliseconds	1·4	0·4	0·1	0·4	0·1
Percentage (from curve C, Fig. 3B)	100	71	60·2	—	—
Calculated closed-circuit milliseconds [from equation (5)] ..	3·52	3·52	3·52	3·52	3·52
Actual closed-circuit milliseconds	3·52	2·5	2·12	3·52	3·52
Total period, milliseconds	4·92	2·9	2·22	3·92	3·62
Sparking frequency	203	345	450	255	276
$\dfrac{\text{Open circuit period}}{\text{Total period}}$	0·285	0·138	0·045	0·102	0·0276

The calculated curve of Fig. 2A was obtained from the equation $V = V_0(1 - e^{-Rt/L})$, which is similar to equation (1) but with V_0 = 14 300 volts.

The curves of Fig. 5B show that the calculated maximum sparking frequency increases from 150–190 sparks per sec. with a single contact-breaker, to 400–500 sparks per sec. with a double contact-breaker having the limiting open-circuit period of 0·1 millisec.

(14) PRACTICAL LIMIT OF SPARKING FREQUENCY

The practical limit of sparking frequency can be deduced from Fig. 5B if the limiting value of maximum current is assumed, and the minimum period of open circuit possible for reliable operation is known.

It has been found that with tungsten contacts the break current at normal engine speed should not exceed 2·5–3·0 amperes, even if the break is apparently sparkless at 4·0 amperes with new contacts. Above 2·5–3·0 amperes oxidation becomes serious, and causes the contact resistance and the tendency to arc to increase. The effect is cumulative, and results in a progressive diminution of performance unless the contacts are frequently cleaned. The break current could exceed 3·0 amperes with platinum-iridium contacts without serious oxidation occurring, but the unidirectional current would tend to cause erosion and "piling-up" at the contacts, and frequent adjustment would be necessary. It is therefore considered that the maximum current should not exceed 4·0 amperes, the break current at maximum and normal engine speeds being about 2·6 and 3·0 amperes respectively.

The minimum period of open circuit for reliable operation is the least period it is possible to use without undue risk of one contact breaker closing before the spark due to the break of the other has occurred. For a double contact-breaker in which the fibre heels are arranged on opposite sides of the cam, it is considered that an open-circuit period of 16·7 per cent of the total period is the practical minimum. This corresponds to 5° for a 12-cylinder engine, and is the angle used in the system employed by the author. In obtaining this limit, allowance is made in a 12-cylinder system for 1° decrease in the open-circuit angle of each contact breaker due to wear of fibre heel, 1° error in the cam crests, and 1° for errors in adjustment, the remaining 1° being the approximate angle during which the secondary voltage is rising to the sparking voltage. Fig. 5B shows that the limiting frequency for 4 amperes and 16·7 per cent open-circuit period is 315 sparks per sec. The value of the open-circuit period is 0·53 millisec.

The minimum open-circuit period of a double contact-breaker in which the fibre heels are mounted on the same side of the cam can be reduced to 13·3 per cent of the total period, corresponding to 4° on a 12-cylinder engine, since the 1° error in the cam crests can be neglected. The limiting frequency for 13·3 per cent is 350 sparks per sec. for a maximum current of 4 amperes. A double contact-breaker in which the fibre heels are mounted on the same side of the cam is not so convenient since the fibre heels must be disposed axially and, considering the rocker-arm type of contact breaker, the axial length of pivot and cam must be increased.

(15) EFFECT OF COIL DESIGN

The experimental results from which the curves of Fig. 5B have been calculated were obtained on a modern coil, and further increase in sparking frequency due to reduction of coil losses would be small. The secondary inductance of the coil was 34·9 henrys, and some increase in performance at low speeds might be obtained under a load of 0·2 megohm by reducing to about 25 henrys. At high speeds the increase due to the persistence of the spark discharge would presumably be smaller owing to a reduction in the duration of the discharge. Thus the alteration in the limit of sparking frequency due to alteration of secondary inductance would appear to be negligible.

The primary inductance of the coil was 7·17 millihenrys. The curves of Fig. 5A, which are drawn for a maximum current of 4 amperes, show that the value of primary inductance for a break current at maximum speed equal to 65 per cent of the maximum current is about 10·2 millihenrys. This increase in primary inductance would presumably produce a slight increase in the high-speed performance owing to an increase in the duration of the discharge, but the increase in sparking frequency would be small.

It would appear that the ultimate frequency of 12-volt coil systems with double contact-breakers capable of meeting Service specification requirements cannot greatly exceed 300 sparks per sec., since the curves of Fig. 5B assume a contact-breaker efficiency of 100 per cent. The broken-line curve of Fig. 2A was obtained by increasing the voltage of the curve for 250 $\mu\mu$F plus 0·2 megohm in the ratio of 4 to 3·1, and thus shows what the performance of the system employed for 14·8 volts, 4 amperes, would be if the contacts could deal with 4 amperes satisfactorily. The limiting frequency under these conditions is 310 sparks per sec., i.e. about equal to the calculated ultimate limit for 12 volts.

(16) EXTERNAL PRIMARY RESISTANCE: EFFECT OF ENGINE CONDITIONS

The limits of sparking frequency shown in Fig. 5B have been estimated on the assumption that any external primary resistance used to avoid an unduly large coil would be of a material having a negligible temperature coefficient. The use of a resistance with a high temperature coefficient is not recommended for a maximum power of 48 watts, since it is considered that this resistance would not respond quickly enough to changes in engine speed, and excessive current would be experienced, due to a sudden fall in speed, before the resistance heated up. Thus to avoid violent sparking the maximum current would have to be reduced below 4 amperes, and the gain in the limiting frequency would be small.

The effect of engine conditions of operation on the limits of sparking frequency have not been investigated. It is probable, however, that the limiting frequency would be slightly lower under engine conditions, owing to a slight decrease in the duration of the discharge.

(17) CONCLUSIONS

(i) The effect of the persistence of the spark discharge is to reduce the closed-circuit period necessary for the primary current to build up to a given value. As the period of open circuit is decreased the necessary closed-circuit period also decreases.

(ii) The effect is approximately independent of secondary loading due to normal values of shunted capacitance, and/or resistance, provided the gap is at its limiting voltage for regular sparking corresponding to the particular load.

(iii) A low value of shunted resistance, due to a breakdown in sparking-plug insulation, may not diminish the intensity of the following spark, but missing on one gap due to a high voltage caused by erosion of the sparking-plug electrodes may produce missing on as many as the three following gaps also.

(iv) For a given performance, the maximum sparking frequency is obtained when the constants of the primary circuit are so designed that the break current, at the limiting frequency, is approximately 65 per cent of the maximum current.

(v) The estimated increase in sparking frequency due to the persistence of the spark discharge, with the break current equal to 65 per cent of the maximum current, is 35 per cent for an open-circuit period of 0·4 millisec., and 63 per cent for 0·1 millisec.

(vi) The ultimate limit for reliable operation of 12-volt coil systems with double contact-breakers, capable of meeting Service specification requirements, cannot greatly exceed 300 sparks per sec. per coil, assuming a maximum current of 4 amperes. The corresponding limit for a single contact-breaker is 170 sparks per sec.

The work described in this paper was carried out at the Royal Aircraft Establishment, South Farnborough, and permission for its publication has been granted by the Director of Research, Air Ministry. The author desires to express his indebtedness to Dr. G. E. Bairsto, in whose Department the work was performed, for advice during the course of the investigation.

DISCUSSION ON
"THE EFFECTS OF IMPULSE VOLTAGES ON TRANSFORMER WINDINGS"*

IRISH CENTRE, AT DUBLIN, 26TH NOVEMBER, 1936

Mr. J. C. Costello: The authors mention that the subject of end-turn reinforcement is at present being investigated for the Electrical Research Association by Mr. Perry, and that they have therefore not investigated it in the detail warranted by its importance. Nevertheless, they have dealt with the question to some extent in the paper, and I wish to put forward some theoretical analyses of the effects of such reinforcement.

Let C, K, and L, be the shunt capacitance, series capacitance, and *effective* inductance per unit length of winding (unit length of winding meaning unit number of turns and not unit axial length of stack). The distance of any point from the neutral is x, and a, b, and l respectively are the distances of ends of the body of winding, intermediate end-turn reinforcement, and extreme end-turn reinforcement (end of winding). The symbol α (with suffix 0 referring to neutral end and suffixes 1, 2, 3 to sections of winding) denotes the value of $l\sqrt{(C/K)}$ at the point indicated by the suffix, i.e. the value which $\sqrt{(C_g/C_s)}$ would have if C and K had, throughout, their actual values at the point in question. Finally, e, g, and ϵ, denote respectively voltage, voltage gradient, and mean inter-turn electric stress, while δ denotes inter-turn insulation thickness.

The following physical assumptions are made: (1) L, C, K, and δ, are uniform throughout any section except where otherwise stated. (2) K is assumed inversely proportional to δ. [From (1) and (2) it follows that voltage between turns is proportional to g, and mean electric stress ϵ is proportional to Kg or g/δ]. (3) C is assumed to: (i) vary inversely as K, so that CK remains constant throughout (in this case α varies as $1/K$, i.e. directly as δ); (ii) remain constant throughout (in this case α varies as $1/\sqrt{K}$, i.e. as $\sqrt{\delta}$).

The true condition as regards C probably lies between (i) and (ii), but nearer to (i): this is supported by the fact that $\sqrt{(C_g/C_s)}$ varies little between different uniform windings.

On these assumptions the initial distribution can be readily found for a variety of cases. Over any length in which C and K are constant the potential is given by

$$e = A\sinh(\alpha x/l) + B\cosh(\alpha x/l)$$

and the corresponding series current by

$$i = \frac{K\alpha p}{l}\frac{\partial e}{\partial x} = \frac{K\alpha p}{l}g$$

where p is the operator $\partial/\partial t$. The constants for the various sections are obtained from the terminal conditions for e and the conditions of continuity of e and i at the junctions of the various sections. The results in a few cases are given below, with numerical calculations for a typical 33-kV transformer reinforced according to B.S.S. No. 422—1931 (33 kV is chosen for mathematical simplicity and greater likelihood of availability for experimental work). For brevity, only the expressions for g are written down, and these only for the case of an earthed neutral; the expressions for e can be written down by inspection, and those for e and g for isolated neutral also follow easily.

Case A_1.—3-section winding, each section uniform, $\sqrt{(C_1K_1)} = \sqrt{(C_2K_2)} = \sqrt{(C_3K_3)}$.

$$g_1 = \frac{\alpha_1 A}{l}\cosh\frac{\alpha_1 x}{l}$$

$$g_2 = \frac{\alpha_2 A}{l}\cosh\left[\frac{\alpha_2 x}{l} - (\alpha_2 - \alpha_1)\frac{a}{l}\right]$$

$$g_3 = \frac{\alpha_3 A}{l}\cosh\left[\frac{\alpha_3 x}{l} - (\alpha_3 - \alpha_2)\frac{b}{l} - (\alpha_2 - \alpha_1)\frac{a}{l}\right]$$

where $A = E/\sinh\left[\alpha_3 - (\alpha_3 - \alpha_2)\frac{b}{l} - (\alpha_2 - \alpha_1)\frac{a}{l}\right]$

For numerical calculation, $\alpha_1 = 8$, $\alpha_2 = 20$, $\alpha_3 = 32$, $\delta_2 = 2\cdot5\delta_1$, $\delta_3 = 4\delta_1$, $a/l = 0\cdot97$, $b/l = 0\cdot99$.

Case A_2.—3-section winding, each section uniform, $C_1 = C_2 = C_3$.

$$g_1 = \frac{\alpha_1 A}{l}\cosh\frac{\alpha_1 x}{l}$$

$$g_2 = \frac{\alpha_2 A}{l}\left[\sinh\frac{\alpha_1 a}{l}\sinh\frac{\alpha_2(x-a)}{l} + \sqrt{\left(\frac{K_1}{K_2}\right)}\cosh\frac{\alpha_1 a}{l}\cosh\frac{\alpha_2(x-a)}{l}\right]$$

$$\begin{aligned} g_3 = \frac{\alpha_3 A}{l}\Bigg[& \sinh\frac{\alpha_1 a}{l}\cosh\frac{\alpha_2(b-a)}{l}\sinh\frac{\alpha_3(x-b)}{l} \\ & + \sqrt{\left(\frac{K_1}{K_2}\right)}\cosh\frac{\alpha_1 a}{l}\sinh\frac{\alpha_2(b-a)}{l}\sinh\frac{\alpha_3(x-b)}{l} \\ & + \sqrt{\left(\frac{K_2}{K_3}\right)}\sinh\frac{\alpha_1 a}{l}\sinh\frac{\alpha_2(b-a)}{l}\cosh\frac{\alpha_3(x-b)}{l} \\ & + \sqrt{\left(\frac{K_1}{K_3}\right)}\cosh\frac{\alpha_1 a}{l}\cosh\frac{\alpha_2(b-a)}{l}\cosh\frac{\alpha_3(x-b)}{l}\Bigg] \end{aligned}$$

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* Paper by Dr. T. E. ALLIBONE and Messrs. D. B. McKENZIE and F. R. PERRY (see page 117).

where

$$A = E\Big/\Bigg[\sinh\frac{\alpha_1 a}{l}\cosh\frac{\alpha_2(b-a)}{l}\cosh\frac{\alpha_3(l-b)}{l} + \sqrt{\left(\frac{K_1}{K_2}\right)}\cosh\alpha_1 a\sinh\frac{\alpha_2(b-a)}{l}\cosh\frac{\alpha_3(l-b)}{l} + \sqrt{\left(\frac{K_2}{K_3}\right)}\sinh\frac{\alpha_1 a}{l}\sinh\frac{\alpha_2(b-a)}{l}\sinh\frac{\alpha_3(l-b)}{l} + \sqrt{\left(\frac{K_1}{K_3}\right)}\cosh\frac{\alpha_1 a}{l}\sinh\frac{a_2(b-a)}{l}\sinh\frac{\alpha_3(l-b)}{l}\Bigg]$$

For numerical calculation, $\alpha_1 = 8$, $\alpha_2 = 8\sqrt{2\cdot 5} = 12\cdot 65$, $\alpha_3 = 16$, $\delta_2 = 2\cdot 5\delta_1$, $\delta_3 = 4\delta_1$, $a/l = 0\cdot 97$, $b/l = 0\cdot 99$.

Case A_3.—3-section winding, sections 1 and 3 uniform, section 2 having δ uniformly graded from δ_1 to δ_3

$$\left[\delta_2 = \delta_1\left(1 + k\frac{x-a}{b-a}\right),\ \text{where } k = \frac{\delta_3 - \delta_1}{\delta_1}\right],$$

$$\sqrt{(C_1K_1)} = \sqrt{(C_2K_2)} = \sqrt{(C_3K_3)}.$$

$$g_1 = \frac{\alpha_1 A}{l}\cosh\frac{\alpha_1 x}{l}$$

$$g_2 = \frac{\alpha_1 A}{l}\left(1 + k\frac{x-a}{b-a}\right)\cosh\left[\frac{\alpha_1 x}{l} + \frac{\alpha_1 k(x-a)^2}{2l(b-a)}\right]$$

$$g_3 = \frac{\alpha_1 A}{l}(1+k)\cosh\left[\frac{\alpha_1 b}{l} + \frac{\alpha_1 k(b-a)}{2l} + \frac{\alpha_1(1+k)(x-b)}{l}\right]$$

where

$$A = E/\sinh\left[\frac{\alpha_1 b}{l} + \frac{\alpha_1 k(b-a)}{2l} + \frac{\alpha_1(1+k)(x-b)}{l}\right]$$

For numerical calculation, $\alpha_1 = 8$, $k = 3[\alpha_3 = 32$, $\delta_3 = 4\delta_1]$, $a/l = 0\cdot 97$, $b/l = 0\cdot 99$.

Case B_1.—Winding uniformly graded throughout, $\sqrt{(CK)} = \text{constant}$, $\delta_x = \delta_0(1 + kx/l)$ where $k = (\delta_l - \delta_0)/\delta_0$.

$$g_x = \frac{\alpha_0 A}{l}\left(1 + \frac{kx}{l}\right)\cosh\left(\frac{\alpha_0 x}{l} + \frac{\alpha_0 kx^2}{2l^2}\right)$$

where $A = E/\sinh\alpha_0\left(1 + \frac{k}{2}\right)$.

For numerical calculation, $\alpha_0 = 8$, $k = 3(\alpha_l = 32)$.

Case B_2.—Winding uniformly graded throughout $[\delta_x = \delta_0(1 + kx/l)]$, C = constant.

The simplest formulae for this case take the form of an infinite series the convergence of which is unfortunately slow for the likely values of the variables. The convergence may be improved by picking out the terms representing $\sinh\alpha_0 x/l$, when the remaining terms give the effect of the increasing insulation thickness. The formulae thus simplified are:—

$$e = A\left[\sinh\frac{\alpha_0 x}{l} + \frac{k\alpha_0}{2!}\left(\frac{x}{l}\right)^2 + \frac{4k\alpha_0^2}{4!}\left(\frac{x}{l}\right)^4 + \frac{4k^2\alpha_0^3}{5!}\left(\frac{x}{l}\right)^5 + \frac{9k^2\alpha_0^4}{6!}\left(\frac{x}{l}\right)^6 + \frac{28k^2\alpha_0^5}{7!}\left(\frac{x}{l}\right)^7 + \frac{(16k\alpha_0^7 + 28k^3\alpha_0^5)}{8!}\left(\frac{x}{l}\right)^8 + \dots\right]$$

Table A

		Section 1								Section 2			Section 3		
x/l		0	0·2	0·4	0·6	0·7	0·8	0·9	0·97	0·97	0·98	0·99	0·99	0·995	1·00
Uniform winding	$g_x/g_{av} = \epsilon_x/\epsilon_{av}$	0·005	0·014	0·067	0·326	0·730	1·62	3·60	6·29		6·82	7·39		7·69	8·00
A_1	g_x/g_{av}	0·003	0·008	0·041	0·202	0·449	1·00	2·23	3·89	9·79	11·89	14·52	23·24	27·26	32·0
	ϵ_x/ϵ_{av}	0·003	0·008	0·041	0·202	0·449	1·00	2·23	3·89	3·89	4·75	5·81	5·81	6·81	8·00
A_2	g_x/g_{av}	0·003	0·009	0·047	0·230	0·512	1·14	2·54	4·43	10·75	11·72	12·83	20·57	21·62	22·82
	ϵ_x/ϵ_{av}	0·003	0·009	0·047	0·230	0·512	1·14	2·54	4·43	4·30	4·69	5·12	5·14	5·40	5·70
A_3	g_x/g_{av}	0·003	0·008	0·041	0·202	0·449	1·00	2·23	3·89		10·86	22·52		26·44	32·0
	ϵ_x/ϵ_{av}	0·003	0·008	0·041	0·202	0·449	1·00	2·23	3·89		4·34	5·63		6·61	8·00
B_1	g_x/g_{av}	0·000	0·000	0·000	0·000	0·005	0·089	1·24	4·55		16·1	23·8		27·0	32·0
	ϵ_x/ϵ_{av}	0·000	0·000	0·000	0·000	0·002	0·026	0·34	1·16		4·08	6·00		6·78	8·00

$$g = \frac{\alpha_0 A}{l}\left[\cosh\frac{\alpha_0 x}{l} + \frac{k}{1!}\left(\frac{x}{l}\right) + \frac{4k\alpha_0^2}{3!}\left(\frac{x}{l}\right)^3 + \frac{4k^2\alpha_0^2}{4!}\left(\frac{x}{l}\right)^4 \right.$$
$$+ \frac{9k^2\alpha_0^3}{5!}\left(\frac{x}{l}\right)^5 + \frac{28k^2\alpha_0^4}{6!}\left(\frac{x}{l}\right)^6$$
$$\left. + \frac{(16k\alpha_0^6 + 28k^3\alpha_0^4)}{7!}\left(\frac{x}{l}\right)^7 + \ldots\right]$$

where A is determined by the condition that $|e|_{x=l} = E$. For the numerical calculation $\alpha_0 = 8$, $k = 3$, with which values the convergence of the series is found to be too slow for accurate computation.

In Table A the values of the gradients g_x and the inter-turn electric stress ϵ_x are given as multiples of the *average* values $g_{av}(\equiv E/l)$ and ϵ_{av}. It will be apparent from these results that the reduction in maximum turn stress is at best very small, and in general negligible if, as is usual, the additional end-turn insulation consists principally of additional thickness of paper having the same electric strength as that in the body of the winding. A point of some importance which emerges is that the effect of increasing the proportion of turns reinforced is extremely small.

With regard to the question of internal oscillations, it appears from an approximate preliminary analysis that the amplitude of these is increased, as would be expected. The frequency is, however, no longer the natural frequency of one unit LCK network, with its harmonics, but comprises fundamentals of several frequencies, each with its harmonics, giving, in the case of a graded winding, a doubly infinite system of frequencies. In my opinion, however, the harmonics are unlikely to be seriously emphasized by non-uniform end reinforcement, and the more important feature is that the initial stress rises practically as much as the reinforcement increases the strength.

It is apparent, of course, that if the end-turn strength could be increased without increasing C/K, i.e. preserving the same insulation thickness, the result would be very useful, but the permittivity of the stronger insulation would require to be approximately the same as that of the normal paper and oil, to avoid concentration of voltage on ducts, etc. There would appear to be possibilities of utilizing mica, which has a permittivity as low as 2·5 in some cases, as compared with 2·0 to 2·6 for paper and about the same for oil.

In conclusion, I suggest that it would be desirable to measure the initial voltage distribution on actual windings with each coil cut, so as to render capacitances alone effective, as the theoretical assumptions are somewhat far from the real conditions (although it appears from the numerical calculations given that considerable variation may be made with relatively little effect).

THE AUTHORS' REPLY TO THE DISCUSSIONS AT LEEDS, BIRMINGHAM, MANCHESTER, BELFAST, AND DUBLIN*

Dr. T. E. Allibone and Mr. D. B. McKenzie (*in reply*): Mr. Atkins has put forward a good alternative method of determining the natural frequency and damping of a winding. Both these factors are of importance; but to ascertain the actual voltage to earth at any given point, and also the voltage difference between adjacent turns and coils, would be a tedious process from the information gained by his suggested technique, and the direct oscillographic measurement is, we feel, superior.

With regard to the behaviour of a winding between tapping points to which condensers are connected, we would first refer Mr. Atkins to our reply to Mr. Stigant (see page 172). To pursue the matter further we must differentiate between windings without reinforced coils and those with one or more reinforced coils. Dealing first with the uniform winding, strap or bobbin-wound type of coils, reference to Fig. 25(*a*) will show that at coil junctions (4·2 per cent, 8·4 per cent, 12·5 per cent) the high-frequency oscillations are not present, i.e. with respect to these oscillations coil junctions are voltage nodes; and it can be shown that the oscillations are half-wave oscillations, the middle of the coil oscillating with respect to its ends. From this it follows that the natural period of oscillation of a coil is not affected by placing a condenser across its ends, but the amplitude is changed.

When, however, a reinforced coil precedes a coil stack of normally-insulated coils, matters are greatly changed. If the reinforced coil has the same external dimensions as the normal coil it will have fewer turns and a higher natural frequency of self-oscillation of the half-wave type. Moreover, at the first coil junction—reinforced coil/normal coil—there is no longer a voltage node. Violent oscillations are present of a frequency almost equal to that observed at one end of the reinforced coil supported in free space to which an impulse is applied at the other end; these oscillations, similar to those at the neutral of an isolated neutral winding, may be conveniently referred to as oscillations of the quarter-wave type and are obvious in Fig. 25(*b*). Apparently in a stack of uniform coils these quarter-wave oscillations cancel one another in adjacent coils, resulting in voltage nodes at coil junctions as described above, but in the heterogeneous winding they do not. The oscillations are then traceable through two or three adjacent normal coils until they eventually become negligible. They are present in the middle of the reinforced coil, and, in addition, the half-wave type oscillations are there in small amplitude, as can also be seen in the second oscillogram of Fig. 25(*b*). When condensers are placed across coils of a heterogeneous winding all the quarter-wave oscillations change their frequency very considerably, and their amplitudes are reduced (to negligible magnitude if the added capacitance is large); the half-wave type oscillations are not changed in frequency and their amplitudes are not so greatly reduced. These points do not seem to have received attention hitherto, but the above is a reason why static end-rings reduce the voltages across end-coils more if these coils are reinforced than if they are normal coils for which the quarter-wave type oscillations do not exist. It would be interesting to construct a reinforced coil with added *internal* capacitance of such a magnitude that its natural period of oscillation would be identical with that of normal coils; presumably, then, the quarter-wave oscillations would balance those of the normal coils, resulting once more in a voltage node at the reinforced-coil/normal-coil junction.

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* The Leeds, Birmingham, Manchester, and Belfast discussions will be found on pages 157 to 171 inclusive, and the Dublin discussion on page 342.

The above discourse is summarized in Table B. Oscillograms already published in the paper demonstrate the salient points.

These oscillations of reinforced coils injected into adjacent coils are responsible for the considerable increase in voltage appearing across those coils. In the 5 000-turn winding described on page 122 the voltage across the 1st coil and also across the 2nd coil reached 38 per cent of the applied impulse; but when the 1st coil was reinforced as described on page 137, the voltage across that coil fell to 32 per cent, and 51 per cent appeared across the 1st normally-insulated coil subsequent to the reinforced coil.

mentioned sparking at the neutral of isolated systems, sparkover taking place on bushings of the same size as used on the line terminals. It should be noted that nearly all star-connected transformers virtually have isolated neutrals, because, even on earthed systems, it is customary only to connect one of a number of transformers to earth, and if the others are a few miles away they behave to surges as though the neutral of the system were isolated.

Mr. Bailey's cited example shows that a surge of about 200 kV appeared at the neutral: we should infer that the 11-kV line was a very highly insulated line. That these high voltages appear at the neutral is proof that wave-tails long compared with half the fundamental period of oscillation of the transformer arise on lines, thus justifying our use of a 110-microsecond wave-tail, as mentioned in our reply to the discussion before The Institution (see page 171). Mr. Bailey also mentions that breakdowns occur within the body of a winding: we think that he is correct in ascribing this to higher gradients arising from discontinuities, since for simple windings without reinforcement or discontinuities the highest gradients appear at the beginning of the winding.

Table B

TABLE OF VOLTAGE WAVE-FORMS APPEARING NEAR THE LINE END OF WINDING FOR (*a*) AND (*b*)

Location of tap to oscillograph	(*a*) Normally-insulated coils	(*b*) One reinforced coil followed by normally-insulated coils
(1) Line end of winding	Applied impulse	Applied impulse
(2) Centre of 1st coil. .	Modified impulse + $\frac{1}{2}$-wave oscillations of a coil	Modified impulse + $\frac{1}{2}$-wave oscillations of a reinforced coil + $\frac{1}{4}$-wave oscillations of a reinforced coil
(3) End of 1st coil . .	Modified impulse: no $\frac{1}{2}$-wave or $\frac{1}{4}$-wave oscillations	Modified impulse: no $\frac{1}{2}$-wave oscillations of a reinforced coil. $\frac{1}{4}$-wave oscillations of a reinforced coil, largest amplitude
(4) Centre of 2nd coil	Further modified impulse: probably $\frac{1}{2}$-wave oscillations of smaller amplitude than in (2)	Further modified impulse + $\frac{1}{2}$-wave oscillations of a normally insulated coil + $\frac{1}{4}$-wave oscillations of the reinforced coil but of smaller amplitude than in (3)
(5) End of 2nd coil . .	Much modified impulse, no $\frac{1}{2}$-wave or $\frac{1}{4}$-wave oscillations	Much modified impulse: no $\frac{1}{2}$-wave oscillations. $\frac{1}{4}$-wave oscillations of reinforced coil still apparent but of smaller amplitude
(6) End of 3rd coil . .	Ditto	Ditto, but smaller or negligible amplitude of $\frac{1}{4}$-wave oscillations of reinforced coil

If a tapping is taken from each coil to a condenser, it is difficult to see how such an arrangement can be inferior to the system of distributed capacitors mentioned by Mr. E. J. Mackenzie; indeed, it might be greatly superior to that system in that the values of the added capacitances are theoretically unlimited, whereas there is a finite limit to the capacitances which can be added by means of shields.

We agree with Mr. Mackenzie that the latitude of 30° in synchronizing the impulse with the crest of the power-frequency voltage is generous; it will doubtless be reduced ultimately, unless the verdict of experience is that the excitation of the winding is redundant. It is interesting to note that whilst the American specification calls for a positive impulse to be synchronized with the negative crest of the power-frequency wave, the Russian draft specification* calls for a negative impulse; this is the more logical as lightning strokes are mainly of negative polarity.

Mr. Field will notice that several other contributors

With regard to Mr. Charley's remarks on Petersen coils, it must be remembered that these coils usually have a high surge impedance, so that the connection of a coil to the neutral of a star-connected winding will not appreciably influence the surge voltage appearing at that neutral. Sparkover can only be prevented, therefore, by some voltage-limiting device being placed across the Petersen coil. Of course only a small fraction of all surges will have the requisite amplitude and wave-tail to result in sparkover occurring at the neutral; for all other surges causing single-phase sparkover on the transmission lines, the Petersen coil will afford the customary protection.

We note Mr. Wilkinson's remarks with great interest. There is one main difference between a transformer and a cable; in a transformer of concentric-winding design there is capacitance between the line and neutral terminals, so that the disturbance at the line is propagated to the neutral with the speed of wave propagation in the dielectric; whereas in a cable there is no such capacitance and a disturbance has to travel along the cable. If the winding is of the sandwich type, then the capacitance of the line to the neutral would be very greatly reduced, i.e. α would be very large and the behaviour analogous to that of a cable.

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* A. V. PANOFF, G. N. PETROFF, and V. A. KARASEFF: *Elektrichestvo*, 1936, No. 5, p. 21.

We agree with Mr. Myers that continuous research on model transformers will give the design engineers valuable help, but the final proof of the insulation strength lies in putting the winding to test: this is the basic principle underlying all type tests. We believe that the problem of detecting faults under impulse tests will resolve itself. Already there are several fairly reliable methods available, and with the growth of experience one or other of these will become standardized. In far older pressure tests there still remains a doubt as to whether damage has been done to the insulation during the test, so it is not to be wondered that so many engineers view the impulse test with suspicion.

Mr. Thomas's remarks on the effect of a discontinuity are interesting and may be contrasted with Mr. Robinson's views set out on page 169. We pointed out on page 137 that the winding was uniform, whereas, when tap-changing mechanism has to be introduced, the insulation between the free ends of the two halves of the winding has to be greatly reinforced for the higher power-frequency voltages there encountered. This diminution of capacitance probably explains Mr. Thomas's experience.

Mr. G. W. Carter's oscillograms form an interesting supplement to Sections (5) and (6) of the paper. The frequency of oscillation in the low-voltage winding shown to the right of Fig. H is of course the frequency of oscillation of the high-voltage winding with the neutral point earthed.

We note Mr. Wellings's communication with interest; the cast-in-concrete type of reactor is, as we also have found, very well able to withstand high-voltage surges owing to its low capacitance to earth and low value of α. We have always understood that so little damage is found in voltage transformers that a shielded-type winding is hardly necessary. It is possible to break down such transformer windings repeatedly with impulse voltages and yet observe no ill-effects at power frequencies of twice the service voltage.

We have already referred to Mr. Norris's remarks on our use of wave-tails twice the length of the average value. For our illustrations we have selected records of voltage to earth, because these give the clearest picture of the passage of a surge through a winding, the dependence of this on wave-shape and on transformer connections. We are well aware that breakdowns most frequently occur between turns and coils, but Mr. Norris ignores the fact that the majority of such breakdowns occur within the winding, i.e. away from the end coil or two. Extreme wave-front or tail steepness only augments the voltage across turns at the end of the transformer, and does not affect the voltage across turns in the body of the winding. This is why surge absorbers, flattening a $\frac{1}{5}$-microsecond front to about a 1-microsecond front and a 1-microsecond front to about a 1·2-microsecond front, as they do if in series with line impedance, effect no appreciable reduction in the voltages appearing across turns in the body of the winding due to long wave-tails. A reduction in the value of α, however, affects the voltages throughout the whole winding for all wave-shapes. We hold very reserved views about admitting the necessity for introducing wave-front steepness testing, and fail to understand why, so far as end-turn insulation strength is concerned, the present tests* using a wave of 1-microsecond front and a vertical tail, chopped by a gap, should not suffice. The tail is likely to be steeper than any laboratory-produced wave-front, and the wave is easily produced and defined.

Mr. Hansell has recently put at our disposal a transformer and Petersen coil, and we have verified our forecast that the voltage at the neutral is but little influenced by the presence or absence of the coil. If Petersen coils are to be designed with low insulation level, a surge arrester must be connected from the terminal to earth.

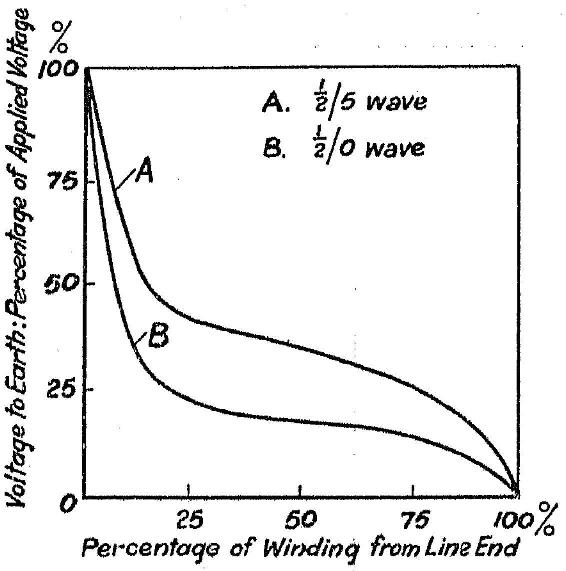

Fig. S.—Comparison of maximum voltages to earth for $\frac{1}{2}/5$ and chopped wave. (Waves chopped just after the crest give maximum voltages to earth between curves A and B.)

Dr. Miller's remarks about Fig. 24, curve C, must be taken with ours about the ratio of the fundamental period to the wave-tail; if this were small, curve C would hold for wave-tails of 40 microseconds. Bewley's remark about the reduction in maximum voltage to earth owing to a 40-microsecond wave relates to a transformer the natural period of which is 100 microseconds; the remark must not be taken out of its context. Voltages appearing on the limbs of multiphase transformers depend on transformer characteristics and on connections [compare Fig. 5 with Fig. 27(iii)C, low-voltage, open- or short-circuited]. One further point should be noted about the ratio of natural frequency of oscillation to wave-tail length, and that is that the natural period of oscillation of the high-voltage winding of an isolated neutral transformer is enormously influenced by short-circuiting (or connecting to cables) the low-voltage winding. This will be referred to later.

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* Reference (38) and others.

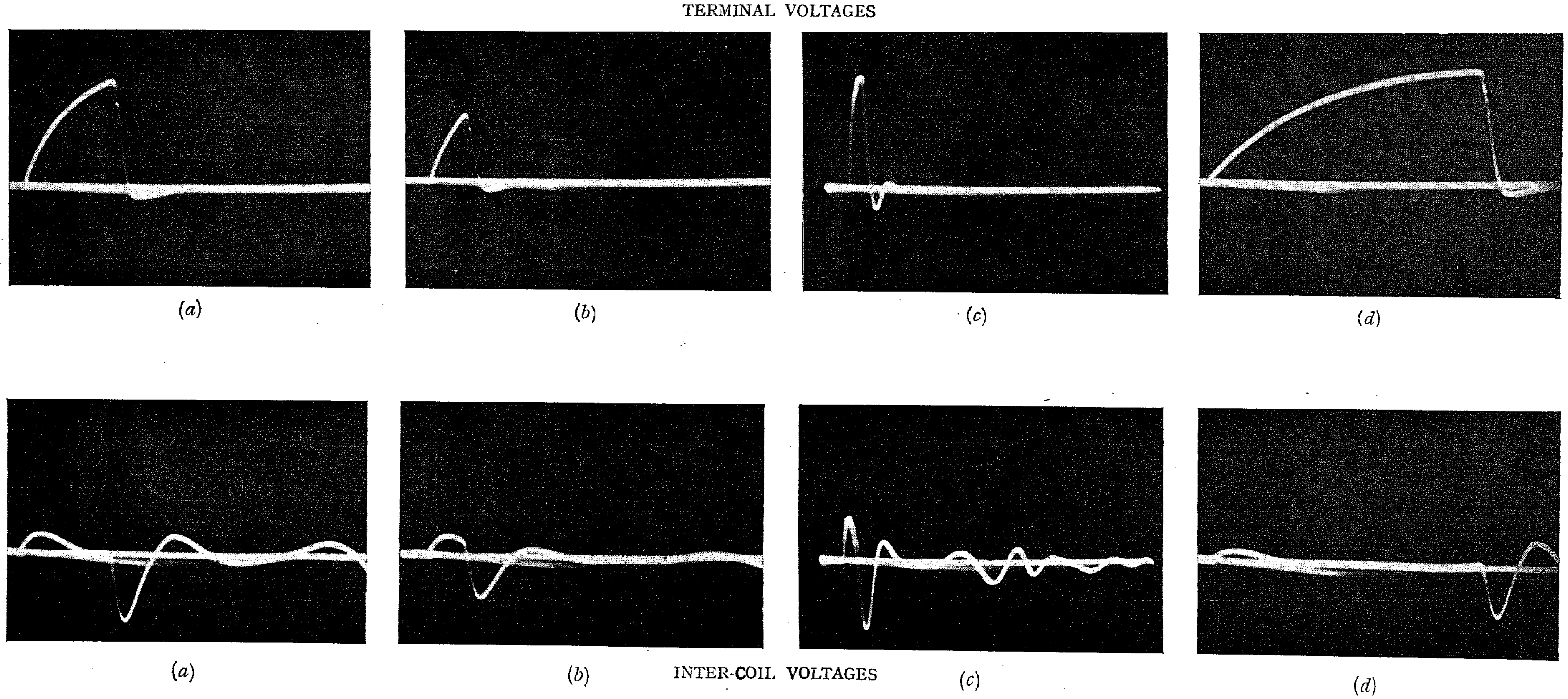

Fig. T.—Oscillograms showing the production of axial stresses in bobbin-coil type transformer (see page 122) by terminal sparkover.

(*a*) Fast-fronted wave: sparkover on crest.
(*b*) Fast-fronted wave: sparkover on rising front of wave.
(*c*) Faster-fronted wave: sparkover on rising front of wave.
(*d*) Slower-fronted wave: sparkover on rising front of wave.

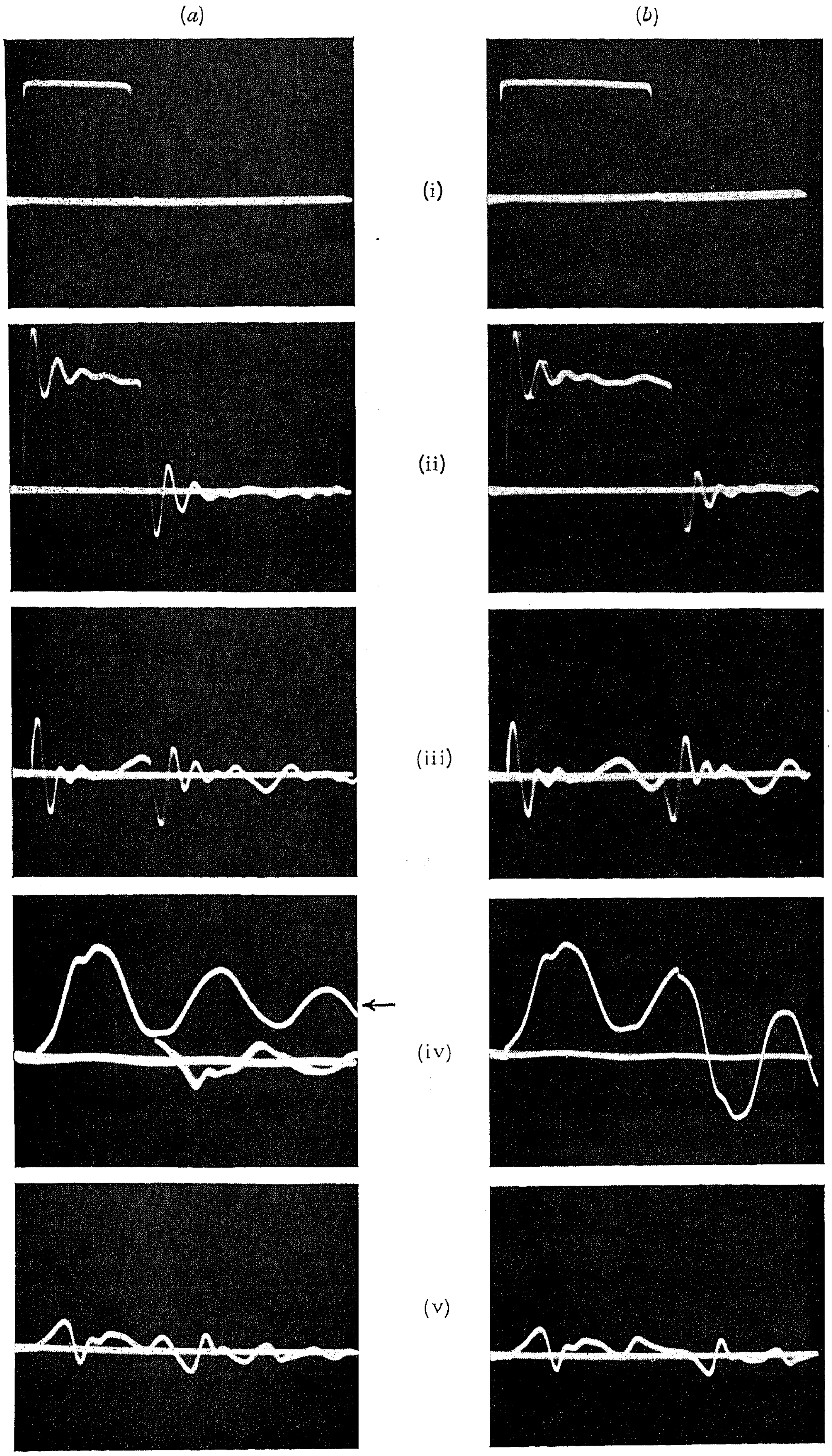

Fig. U.—Oscillograms showing the effect of chopping an impulse subsequent to the crest of the applied impulse.

Impulse chopped as the oscillatory voltage at the centre point of the winding attains (*a*) a minimum value, and (*b*) a maximum value. A 1/1000 wave was used to eliminate confusion due to the exponential wave-tail.

(i) Applied impulse.
(ii) Voltage to earth at 8·3 per cent of winding from line end.
(iii) Voltage across coils 4·2–12·5 per cent of winding from line end
(iv) Voltage to earth at 50 per cent of winding from line end. [*Note:*—Oscillations due to the unchopped wave are also given on the left hand record. (See arrow.)]
(v) Voltage across coils 46–54 per cent of winding from line end.

Dr. Miller rightly takes exception to our statement that a $\frac{1}{2}/5$ wave approximates to a chopped wave, for he is only considering axial stresses at the beginning of the winding; reference to our remarks on page 132 will show, however, that we were referring to voltage to earth throughout the whole of the winding, and, in support of our remarks, curve B in Fig. S is the envelope of maximum voltages to earth appearing in the winding for a $\frac{1}{2}$-microsecond wave chopped on the crest; curve A for a $\frac{1}{2}/5$ wave is given for comparison. We agree that a rapid decline of voltage will produce larger gradients in the end turns than a lower rate of rise of voltage, but that is merely illustrating the change which takes place in the initial distribution, as shown in Fig. 9, during the first fractions of a microsecond, and is explained by the higher amplitude of the higher harmonics produced by a greater rate of change of applied voltage. We have not as yet found any evidence to suggest that the gradients are appreciably affected after the first few per cent of the winding from the line end; although, as mentioned on page 132, the gradient of the earthed neutral may reach, in time, the gradient at the line end, we have never found that to be the case in practice. Figs. K and M show the effect of chopped waves in the end turns very beautifully, and the various possibilities are analysed in Fig. L. Fig. T (see Plate 1, facing page 346) illustrates oscillographically the drawings of Fig. L as applied to the transformer described in the paper, and Fig. U (see Plate 2) extends these to consider chopping after a long time-lag. Mr. Lacey (see page 153) suggests that, after a long time-lag, the effects of chopping are likely to be more serious than after a short time-lag. We have found no evidence in support of this view. After a long time-lag, oscillations have developed throughout the winding as shown in Fig. 13(i), and if a steep chop is then applied, equivalent to the superposition of an impulse of opposite polarity, oscillations of the opposite sense are superimposed on those already in existence.

Fig. U records the voltage at various points in the winding: (i) at the line end, (ii) at 8·3 per cent from the line end, and (iv) at 50 per cent from the line end, these three being recorded with respect to earth. In addition, the voltage (iii) across the coil (4·2–12·5 per cent), and (v) across the coil (46–54·2 per cent), are given. Column (*a*) relates to the wave being chopped as the main oscillation attains a maximum value, and (*b*) as the oscillation reaches a minimum value. It will be seen that the voltage to earth never exceeds with a late-chopped wave the voltage for an unchopped wave; and the voltage across a coil due to chopping (a measure of the gradient in a winding) never exceeds the voltage due to the wave-front (this is true only if the wave-front steepness is as great as the wave-tail steepness; we have endeavoured to make them identical in Fig. U). The reason for the above is that the voltage to earth at the end of the winding at the moment of chopping is never as large as the applied voltage (for late chopping), so that the oscillations and gradients resulting from chopping are never as large as those resulting from the wave-front. As the voltage across a coil reaches its maximum in a very short time, that due to the wave-front is well separated in time from that due to the chopped tail of the wave. The situation within coils follows along the above general lines.

The cure applied to the transformer problem referred to by Mr. Brown is an illustration of one method of eliminating the effects of rapid rate of change of voltage in the winding; the winding is to be provided with condensers at certain tapping points. We agree with Mr. Wilkinson's views about the time-delay before power can be made available at a fault; as Mr. Nuttall remarks on page 167, Karaseff has recently analysed this in detail.

In reply to Mr. Nuttall we can state that, though our experience is very limited on instrument transformers, tests indicate that breakdown between turns of voltage transformers is not followed by power arc, and trouble is more likely then to follow major insulation failure. It is interesting to note that the stethoscope proved to be most valuable in the detection of breakdown in voltage transformers when other methods such as changes in excitation current failed. With regard to current transformers, the straight-through type presents no special features for comment; an impulse test across the major insulation is all that is required. For wound-type current transformers the secondary windings should be short-circuited and earthed; the high-voltage windings may be short-circuited or one may be attached to a condenser simulating the total added capacitance of a typical load during the impulse test of the major insulation between windings. If the design of current transformers is such that the primary windings have considerable inductance, suitable voltage-limiting devices should be placed across the primary windings.

In adjusting the wave-shape of an applied impulse it is our custom to make the adjustments at voltages well below the test or anticipated breakdown voltages. With isolated neutral windings the connection of the low-voltage winding to a power supply considerably reduces the effective inductance of the high-voltage winding and it may be that, with the available capacitance of the impulse generator, the wave-tail of the impulse applied to the winding is shorter than the standard wave. This may be remedied by placing high-frequency choke coils in each of the low-voltage leads; these do not affect the excitation of the winding, but increase the effective inductance of the high-voltage winding and so permit of a longer wave-tail being applied to the winding.

We have not yet had an opportunity of repeating Karaseff's experiments, but the results are in line with our experience given on page 141 and also with the experience of operating and manufacturing engineers who state that punctures frequently found are without any signs of a power arc having followed the surge breakdown.

In reply to Mr. Robinson we admit the error in our statement that C_s decreases with increasing size of transformer: when the core can be no longer increased in height owing to the loading gauge, C_s must increase with voltage and with kVA. A consequence of this error is, however, that the rate of rise of voltage at a terminal point of a transformer is less than that given on page 119, thus mitigating the severity of surges when they reach the winding. The measurements of selected capacitances in a winding do not present difficulties;

but the selection of the capacitances to be used for the derivation of α do. Thus if the low-voltage winding is short-circuited—connected to long low-impedance cables—the ends of the low-voltage winding may be said to be at earth potential, but the central region of the low-voltage winding is not sensibly at earth potential. The component of C_g between the high-voltage winding and the core to be used in the calculation of α is something between the capacitance of the high-voltage winding to the core, and that of the high-voltage winding to the low-voltage winding. On page 139 we note an increased capacitance for C_g, but it was not as large as one expected, pointing to the fact that the low-voltage winding could not be assumed to be at earth potential over its entire length. We refer Mr. Robinson to our reply to Mr. Lacey on page 172 about wave-tail length and period of the winding. The actual value of ω is therefore unimportant in studying the general effects of impulses on windings; short-circuiting a low-voltage winding can make a large difference to ω, as already explained. The remarks on page 138 refer to the model transformer described on page 122.

We greatly appreciate Mr. Robinson's contribution relating to end-turn gradients, and we recognize that these extreme cases can only be investigated by inter-coil oscillograms, the method of differences being inaccurate. An answer to his remarks about gradients due to voltage collapse will be found in an earlier part of our reply. Curves for gradients within the winding are almost identical for a 1/100 wave, a 1/13 wave, and a wave chopped on the crest except in the first coil. In reply to Mr. Robinson's remarks about the surge absorber, we suggest—in the absence of further information relating to the experiments described—that between the impulse generator and the absorber/transformer combination a resistance of a few hundred ohms was placed: if it had not been so, we should expect oscillations in Fig. Q (applied wave) due to the discharge of the generator capacitance into the transformer capacitance; whereas we observe that the circuit was aperiodic. Granted a resistance of, say, 300 ohms, this in combination with a capacitance of $0 \cdot 0005$ to $0 \cdot 005\,\mu$F (the approximate capacitance to earth of oil-immersed or solid-insulation surge absorbers respectively) would obviously slope a steep front or a steep chopped tail to about 1–2 microseconds, as shown in the second record of Fig. Q. The same argument applies to Fig. R, and the facts are easily demonstrated with any transformer and a $0 \cdot 001$-μF condenser connected between the line terminal and earth. But this proves nothing about the protective value of absorbers to surges applied through negligible series impedance directly to an absorber/transformer combination. If the resistance between generator and absorber is, say, 30 ohms, the rate of rise is scarcely affected by the absorber, as we have shown with a surge absorber and the transformer on which most of the work described in the paper was done. The inductance in the absorber is so small that it offers negligible impedance to a wave-front of a fraction of a microsecond, and for such a wave chopped on the rising wave-front we have shown that the protective value of the absorber is nil; indeed, we found an increase in voltage at the transformer terminal and across the first 1 per cent of the winding. A similar result (taken for a steep-fronted wave and long wave-tail) is quoted by Palueff and Hagenguth* and we have verified the accuracy of their measurements.

In reply to Mr. Partridge's query, we ascertained that a 33-kV surge with a $\frac{1}{2}$-microsecond front applied to a gas protector (the d.c. breakdown of which was 360 volts) was held down to $1 \cdot 6$ kV with a time of breakdown of $0 \cdot 1$ microsecond, but as there are so many gas protectors on the market we are afraid that the above isolated statement will not be of much assistance.

We are unable to answer Dr. Gillies's first question. We find extraordinarily accurate agreement between records taken with the recurrent surge oscillograph and with the high-voltage oscillograph; indeed, as yet we have found no disagreement. We would refer Mr. McCandless to the curve of fatigue of oil-immersed pressboard insulation under impulse voltages quoted in our 1935 paper,† and we have reason to believe that most of the solid dielectric used in transformers has a similar fatigue curve. Ten impulses should produce negligible fatigue. We have already referred to the Petersen coil and its effect, and we agree that the most desirable solution is to reduce the arcing horns on incoming lines to values considerably (30 per cent) lower than they are at present. Experience in Great Britain shows that such a decrease would not result in an increased number of outages; with Petersen-coil protection there would probably be no outages, as multiphase faults are not common. Unfortunately, we have no statistics of value to give Mr. Cunliffe on the relative frequency of breakdown at different parts of a winding, but we know that breakdown at the extreme end of the winding is not the commonest form of breakdown.

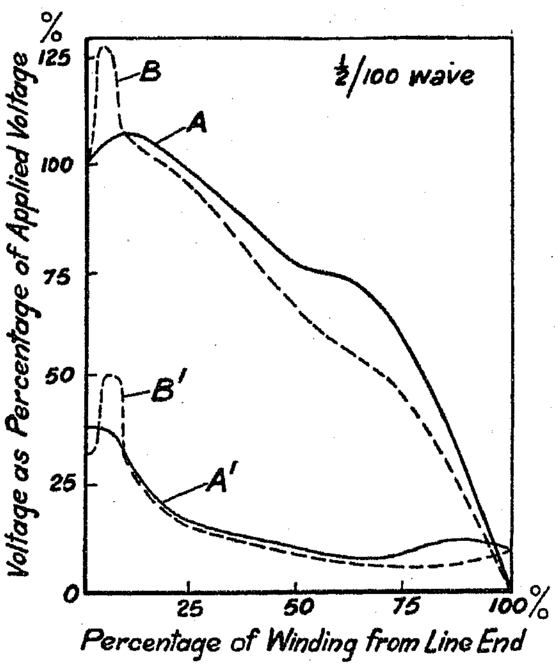

Fig. V

A, B. Maximum voltages to earth for normal and reinforced windings.
A′, B′. Voltages across 4 per cent of winding for normal and reinforced windings.

Note.—One reinforced coil only was placed at the line end of the winding.

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* *Transactions of the American I.E.E.*, 1933, vol. 52, p. 954.

† Page 479 of Reference (38).

We greatly appreciate Mr. Costello's valuable contribution to the study of reinforced end-turn insulation. The analysis is confined to the initial voltage distribution, which, as we have already pointed out, presents some difficulty in measurement. It is also apparently confined to strap-wound coils, since δ (the inter-turn insulation thickness) is assumed to be uniform throughout any section, a condition not fulfilled with bobbin-wound coils. The conclusions are, however, of great importance and deserve careful comparison with experimental results—a comparison which we regret we are unable to make at the present juncture. Mr. Costello's remarks on the natural frequency of internal oscillations of a reinforced section agree with what we have quoted earlier in our reply, but he does not appear to have predicted the injection of these frequencies into normally-insulated coils, nor to have predicted the quarter-wave type of oscillation present at the junction of the reinforced coil and the ordinary coil. As far as we have been able to analyse our results, it appears to us that these oscillations are far more serious than the voltages within reinforced coils. We are certain that the voltages within reinforced coils (of the same general physical dimensions, and therefore of fewer turns than normal coils) are seldom in excess of, and are generally smaller than, the voltages in normal coils; and we find that the voltages measured in normal coils adjacent to reinforced coils are greater than those in the same coils preceded by normally-insulated coils. Fig. V is typical of many curves obtained for the maximum voltage measured across a coil (*a*) throughout a winding uniformly insulated, and (*b*) throughout a winding with reinforced end-turn insulation.

In conclusion we should like to take this opportunity of thanking Mr. G. J. Scoles, B.Sc.(Eng.), and Mr. G. H. Webster, B.Eng., Graduates, for their valuable assistance in the preparation of this reply since one of us (Mr. McKenzie) left the staff of the Metropolitan-Vickers Research Department.

INSTITUTION NOTES

COOPERS HILL WAR MEMORIAL PRIZE AND MEDAL

The triennial award of the above Prize and Medal falls this year to the I.E.E. Council, who have decided to invite eligible members to submit for consideration a paper on any subject coming within the scope of electrical science or electrical engineering and their applications. Papers submitted must be specially written for the purpose of the competition and must reach the Secretary of The Institution not later than the 1st October, 1937. Only Corporate Members who were under 35 years of age on the 1st January, 1937, are eligible.

Full particulars will shortly be circulated to all Corporate Members.

SCHOLARSHIPS

The Secretary desires to draw the attention of members to the following Institution Scholarships:—

Duddell Scholarship (value £150 per annum for 3 years).

Open to British subjects under 19 years of age on the 1st July who have passed a matriculation or equivalent examination, and who desire to take up a whole-time day course in electrical engineering.

Ferranti Scholarship (value £250 per annum for 2 years).

For whole-time research or post-graduate work. Open to British subjects under 26 years of age on the 1st July, who have been Students or Graduates of The Institution for at least 2 years and have taken either (*a*) a whole-time course in electrical engineering of at least 3 years and obtained a degree or diploma; or (*b*) a whole-time course in science of at least 3 years and obtained an honours degree, provided that in the final examination for such degree they have passed in "Physics," or "Electro-Chemistry," or "Electro-Metallurgy."

Swan Memorial Scholarship (value £120 for 1 year).

The conditions are similar to those for the Ferranti Scholarship, except that the age limit is 27 years on the 1st July and that candidates need not be members of The Institution. Preference will be given to candidates who were born in the County Borough of Sunderland, or resided there for at least 7 years, or were educated at Sunderland Technical College.

Silvanus Thompson Scholarship (value £100 per annum, plus tuition fees, for 2 years).

Open to British subjects who have served a minimum apprenticeship (or its equivalent) of 3 years at an approved works and are under 22 years of age on the 1st July, and who desire to take up a whole-time day course in electrical engineering.

William Beedie Esson Scholarship (value £120 per annum, tenable for 2 years, renewable in approved cases for a third year).

Open to British subjects who have served a minimum apprenticeship (or its equivalent) of 3 years at an approved works and are under 22 years of age on the 1st July, and who desire to take up a whole-time day course in electrical engineering.

The closing date for receiving nominations for this year's awards of Scholarships is the 15th April. Any member desirous of obtaining more detailed information should apply to the Secretary.

INFORMAL MEETINGS

193RD INFORMAL MEETING (26TH OCTOBER, 1936)

Chairman: Mr. H. T. Young (President).

Subject of Discussion: "Electrical Installations—Adequacy and Safety" (introduced by Mr. H. T. Young).

Speakers: Messrs. A. Morgan, F. G. Tyack, F. C. Raphael, E. Jacobi, W. Lunn, F. Jackson, W. F. Floyd, B.Sc., R. E. Robson, P. Honey, H. Bright, M.A., E. S. Ritter, C. R. H. Stewart, S. C. Bartholomew, M.B.E. W. E. Wicks, H. E. Knight, J. H. S. Gillingham, B.Sc. (Eng.), E. H. Berry, and E. G. Francis.

194TH INFORMAL MEETING (9TH NOVEMBER, 1936)

Chairman: Mr. S. C. Bartholomew, M.B.E.

Subject of Discussion: "The Relative Costs of Electrification of Rural and Urban Areas" (introduced by Mr. J. A. Sumner).

Speakers: Messrs. A. Morgan, F. Jervis Smith, H. Bright, M.A., J. M. Kennedy, O.B.E., A. N. D. Kerr, A. H. C. Frost, L. M. Jockel, P. P. Wheelwright, P. B. Frost, J. D. Dennison, F. E. Wallcroft, and S. C. Bartholomew, M.B.E.

195TH INFORMAL MEETING (23RD NOVEMBER, 1936)

Chairman: Mr. H. Brierley.

Subject of Discussion: "Electric Vehicles—Some Technical Aspects" (introduced by Mr. L. Murphy).

Speakers: Messrs. W. E. Warrilow, A. Morgan, F. Jervis Smith, H. Bright, M.A., J. H. S. Gillingham, B.Sc.(Eng.), G. F. Bedford, B.Sc., P. P. Wheelwright, C. P. Fox, J. M. Kennedy, O.B.E., C. W. Marshall, B.Sc., S. C. Bartholomew, M.B.E., A. L. Trundle, and W. J. Lloyd.

196TH INFORMAL MEETING (7TH DECEMBER, 1936)

Chairman: Mr. A. F. W. Richards.

Subject of Discussion: "Should the I.E.E. Wiring Regulations be applied to Installations of Thirty Years Ago?" (introduced by Mr. R. Grierson).

Speakers: Messrs. W. R. Rawlings, S. W. Melsom, P. J. Higgs, E. E. Hutchings, F. Jackson, D. St. A. Butcher, A. S. Clarke, M. J. W. Bullard, F. L. Veale, W. Lang, G. Waters, A. Morgan, A. J. Smith, G. Davidson, W. S. Shall, E. T. Batchelor, H. C. Cooper, F. Jervis Smith, and A. F. W. Richards.

197TH INFORMAL MEETING (21ST DECEMBER, 1936)

Chairman: Mr. A. F. Harmer.

Subject of Discussion: "The Maintenance and Conditioning of Electric Cookers" (introduced by Lieut.-Col. H. W. Watts).

Speakers: Messrs. A. N. East, C. W. Hughes, J. J. McKenna, G. H. Fowler, D. St. A. Butcher, F. Jervis Smith, P. P. Wheelwright, Miss B. Samuel, Miss H. Menoprio, Messrs. D. G. W. Ackworth, A. C. H. Frost, W. A. Ritchie, —. Percival, J. R. Kinnersley, and A. F. Harmer.

198TH INFORMAL MEETING (11TH JANUARY, 1937)

Chairman: Mr. Forbes Jackson.

Subject of Discussion: "Emergency Lighting Systems" (introduced by Mr. E. Ridley, M.B.E.).

Speakers: Messrs. J. V. Gil, L. P. Caley, B.Sc.(Eng.), F. Jackson, J. Rose, G. Waters, B.Sc.(Eng.), E. J. Reed, F. G. Sawyer, H. J. W. Bullard, S. H. Chase, S. J. M. Beale, J. H. Leverton, B.Sc.(Eng.), A. Morgan, M. G. Foster, A. F. Hutchen, and E. R. Sanderson.

199TH INFORMAL MEETING (25TH JANUARY, 1937)

Chairman: Mr. N. R. Rice.

Subject of Discussion: "Industrial Temperature Control" (introduced by Mr. D. B. Williamson, B.Sc.).

Speakers: Messrs. A. J. Bousfield, A. B. Stevenson, B.Sc., H. D. Barlow, G. L. Woolnough, B.E., R. W. Griffen, B.Sc., A. Morgan, C. G. Westerhaut, and F. Jervis Smith.

200TH INFORMAL MEETING (15TH FEBRUARY, 1937)

Chairman: Mr. F. Jervis Smith.

Subject of Discussion: "The Value of the Development of the Lighting Load" (introduced by Mr. H. H. Long).

Speakers: Messrs. A. Morgan, P. P. Wheelwright, A. Cunnington, J. B. Harris, D. St. A. Butcher, A. F. W. Richards, S. C. Bartholomew, M.B.E., E. W. Murray, R. Grigg, A. G. Kemsley, M. Whitgift, and F. Jervis Smith.

PROCEEDINGS OF THE WIRELESS SECTION

131ST MEETING OF THE WIRELESS SECTION, 18TH NOVEMBER, 1936

Mr. R. A. Watson Watt, B.Sc.(Eng.), the retiring Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 6th May, 1936, were taken as read and were confirmed and signed.

Mr. Watson Watt announced the Council's award of Premiums (see vol. 78, page 726) for papers read before the Section during the session 1935–36. He then vacated the chair, which was taken by the new Chairman, Dr. E. Mallett.

A vote of thanks to Mr. Watson Watt for his services as Chairman during the session 1935–36, proposed by Mr. A. J. Gill, B.Sc.(Eng.), and seconded by Mr. F. S. Barton, M.A., B.Sc., was carried with acclamation.

Dr. Mallett then delivered his Inaugural Address (see page 174).

A vote of thanks to the Chairman for his Address, proposed by Mr. Watson Watt, was carried with acclamation.

8TH INFORMAL MEETING OF THE WIRELESS SECTION, 24TH NOVEMBER, 1936

Dr. E. Mallett, Chairman of the Section, took the chair at 6.30 p.m.

The minutes of the Informal Meeting held on the 24th March, 1936, were taken as read and were confirmed and signed.

A discussion, opened by Mr. H. B. Swift, took place on "The Scope of the Amateur in the Development of Radio Engineering," and at its conclusion a vote of thanks was accorded to Mr. Swift for his introductory remarks.

132ND MEETING OF THE WIRELESS SECTION, 2ND DECEMBER, 1936

Dr. E. Mallett, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 18th November, 1936, were taken as read and were confirmed and signed.

A paper by Messrs. M. Benjamin, B.Sc., Ph.D., C. W. Cosgrave, B.Sc., Associate Member, and G. W. Warren, B.Sc., entitled "Modern Receiving Valves: Design and Manufacture," was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

133RD MEETING OF THE WIRELESS SECTION, 6TH JANUARY, 1937

Mr. E. B. Moullin, M.A., took the chair at 6 p.m.

The minutes of the meeting held on the 2nd December, 1936, were taken as read and were confirmed and signed.

The following papers (presented by Mr. J. A. Ratcliffe; M.A., on behalf of the authors) were read and discussed:—

"Control of Wireless Signal Variations," by Messrs. A. L. Green, M.Sc., Ph.D., Associate Member, and G. Builder, Ph.D.

"Control of Phase Fading in Long-Distance Radio Communication," by Messrs. A. L. Green, M.Sc., Ph.D., Associate Member, and O. O. Pulley, B.E., Ph.D.

A vote of thanks to the authors, and to Mr. Ratcliffe for presenting the papers, was moved by the Chairman, and was carried with acclamation.

9TH INFORMAL MEETING OF THE WIRELESS SECTION, 26TH JANUARY, 1937

Dr. E. Mallett, Chairman of the Section, took the chair at 6.30 p.m.

The minutes of the Informal Meeting held on the 24th November, 1936, were taken as read and were confirmed and signed.

A discussion, opened by Mr. A. H. Cooper, took place on "What Performance is desirable in Broadcast Receivers, with special reference to Automatic Devices."

At the conclusion of the discussion a vote of thanks was accorded to Mr. Cooper for his introductory remarks.

ELECTIONS AND TRANSFERS

At the Ordinary Meeting held on the 11th February, 1937, the following elections and transfers were effected:—

Elections

Associate Members

Deacon, Allan Stanley.
Golde, Rudolph Heinrich, Dipl. Ing.
Irving, Stanley Carrick.
McCombe, John, Ph.D.
Roberts, Philip Barker, B.A.
Roy, Sadhan Chandra, B.Sc.
Wilkins, William Ernest, B.Sc. (Eng.).

Companion

Seshasayee, Vadamalai.

Associates

Brewin, Frederick John.
Bullard, John.
Fowler, Edward Albert.
Harris, David Jonathan.
Lamb, James Ernest.
Radford, Hector Macleod.
Vaughan, Geoffrey Victor.

Graduates

Brabant, Raymond Robert
Brazel, Edmund Hamilton.
Cameron, Robert Glendinning.
Carlyle, Ronald Stuart.
Cattle, Edward Arthur.
Cooper, Raymond.
Forbes, Ian Stuart, B.Sc. (Eng.).
Freeman, Edward Reykers, B.A.
Gunton, Richard, B.Sc.
Hammond, John Gilham, B.Sc.
MacCallum, John Kelly, B.Sc.
MacKenzie, George, B.Sc.
Moore, Sydney.
Morgan, Edward, B.Sc.
Morris, David Gwilym O.
Morris, Harry.
Newland, Robert Charles.
Penfold, Thomas Bernard D., B.A.
Reardon, John.
Sloane, Robert Wood, B.Sc., M.A., Ph.D.
Smith, Thomas Joseph.
Ward, Kenneth Martin, B.A.

Transfers

Associate Member to Member

Say, Maurice George, Ph.D., M.Sc.

Associate to Associate Member

Bulman, Christopher Howard.
Jeffs, Arthur Joseph.
Logan, Joseph Ambrose.

Graduate to Associate Member

Advani, Motiram Hotchand.
Ashby, Donald, B.Sc.
Bhatia, Hans Raj.
Bray, Victor Henry.
Brigg, Stanley.
de Bruyn, W.
de Villiers, John Henry P.
Elphick, Jonathan Frank.
Forrest, John Samuel, M.A., B.Sc.
Goddard, Maurice Wilfred.
Hallawell, Austin Morris, B.Sc.
Hockmeyer, Ian Otto, B.Sc.Tech.
Jamieson, Douglas.
McCabe, Ernest.
Park, Robert Thomas.
Parker, Frank Dewar.
Raine, John Clitheroe.
Rossler, Albert.
Strawson, Thomas Russell.
Taylour, Henry Horatio, M.Sc.(Eng.).
Turner, John Hill.
Vallance, Derwent Bridson.

Student to Associate

Butcher, Fred. Eric.
Ungoed, William Powell C.

At the Ordinary Meeting held on the 25th February, 1937, the following elections and transfers were effected:—

Elections

Associate Members

Bazalgette, Harry Lautour.
Coode-Adams, William Roy C., M.A., M.Sc., Ph.D.
Palk, Edward.
Paterson, Donald Rose, Capt., R.Signals, M.A.
Peierls, Alfred Heinrich, Dipl.Ing.
Sargeant, Lawrence Krall.
Stern, Walter, Dr. Ing.

Associates

Ashton, Norman.
Britton, Charlie Alistair, B.Eng.
Hales-Downing, Charles Henry.
Horner, Francis Henry.
Prowse, John Albert.
Russell, Benjamin John.
Schuepp, Reginald Hermes.
Wolverson, Frederick Arthur.

Graduates

Allardice, David Rutherford.
Alleway, Charles Edward.
Aucott, Bernard.
Beard, Harold Jenner, B.A.
Biswas, Sudhindra Narayan.
Brocklehurst, Sydney George.
Butler, Albert Edward.
Clarke, George Green.
Connor, Raymond Arthur W.
Cook, Joseph Stanley.
Corbyn, David Benjamin, B.Sc.(Eng.).
Davies, Reginald John.
Edwards, Arthur William J., Dipl.Ing.
Glover, Gerard Joseph.
Goodwin, William.
Gurney, William Albert J.
Hewitson, Harry Bleamire.
Leech, Percy, B.Sc.
Lewis, William Gwynfor.
Livesey-Farr, Alan.
Lobo, Herculano.
McIlwaine, William.
Martin, Ronald Cyril, B.Sc.
Page, Frederick William.
Postle, Sydney Alfred.
Reid, Herbert Raymond.
Richardson, Frank.
Russell-Stracey, Patrick Henry A.
Sharp, Duncan.
Shave, Alan Edward.
Sheppard, Cyril Edward.
Stephens, William Denis.
Thompson, Wilfred.
Tissington, Richard Sydney, B.Sc.
Truefitt, Edward Samuel V.
Vuille, Bernard Andre.
Waldram, Alfred Henry T.
Willcocks, Harold Richard W.

Students

Agnew, William Poole.
Bayes, Geoffrey Santon.
Burdis, Frederick Horace.
Chambers, George Stanley M.
Charles, Robert Frederick.
Colby, William Henry.
FitzGerald, Gerald.
Johnston, James Howard.
Jones, Cyril Victor.
Lamping, Charles Thomas.
Smith, Dennis.
Smith, Peter Geoffrey.
Upson, George Harold.
Wincott, Leslie Moreland.

Transfers

Associate Member to Member

Alvey, George Burton.
Davis, Basil Montefiore J.
Dean, Rennie.
Fowles, Samuel Henry.
Gee, Colin Brooke, B.Sc. Tech.
Goodlet, Brian Laidlaw, B.A.
Jones, Reginald Hugh, M.Sc.
Thorpe, Donal Winton.
Vanneck, Richard Grant.

Associate to Associate Member

Henwood, Henry James.
Love, Henry.

Graduate to Associate Member

Ashworth, Harry Clifford.
Bolt, Frederick Denis, B.Sc.(Eng.).
Brunt, Basil Percival.
Burgess, Raymond Ernest J., B.Eng.
Connon, Edwin William, B.Sc.(Eng.), B.Eng.
Cowlishaw, Alwyn.
Crook, Wilfrid Evelyn.
Crookes, William Raymond.

Graduate to Associate Member—continued

Dunn, Roland Harris, B.Sc.
Glover, Alban Joseph, B.Eng.
Gray, George William.
Haigh, Roland William.
Hancock, Jeffrey.
Hodges, Lawrence Wilfred.
Jagger, John Greenwood. M.A., M.Sc.
Kemp, James, B.Sc.
McGregor, Archibald Andrew D., B.E., B.Sc.
Marsh, John Henry.
Mitry, Wadie, M.Eng.
Murray, Robert Whyte.
Pienne, Adolphe Charles G.
Robinson, James Edwin L., M.Sc.
Rousell, Sydney Michael E.
Sageman, Walter John.
Sloan, George Stephen, B.E.
Small, Frank.
Sumner, Walter.
Taylor, John Alfred.
Tucker, Henry Valon.
Wafa, Elsayed Hassan, B.Sc.

Student to Associate Member.

Mallinson, William David, B.Sc.(Eng.).

The following transfers were effected by the Council at their meeting held on the 11th February, 1937:—

Student to Graduate

Anderson, Ronald George.
Baume, Harold.
Beadle, David Gilbert.
Bell, Maurice.
Bostock, Edward Thomas, B.Eng.
Bryer, Robert Frank, B.Sc.
Carmichael, Ian.
Coysh, James William.
Hawkins, Hubert John.
James, Arthur Jack T.
Jephcott, Cyril Rees.
Last, Francis Herbert.
Mole, John Henry, B.Sc.
Morison, John William.
Onder, Abdul Kerim.
Osborn, Cyril Francis.
Pendleton, Leslie.
Ramamurphy, Subramania Ayyab, B.E.
Reed, Walter Howard.
Rowe, Arthur Cyril, B.Sc.
Shreeve, Alfred George.
Stephenson, Ernest.
Wallis, Alan Mackenzie, B.Sc.(Eng.).
Whitaker, Evald Mattievich, B.Sc.

The following transfers were also effected by the Council at their meeting held on the 25th February, 1937:—

Student to Graduate

Allen, Henry William S.
Bahns, Harold Watts, B.Sc. (Eng.).
Baker, Thomas Buller.
Bell, William.
Benzie, Athol Emslie, B.Sc. (Eng.).
Brighton, Allan Norman, B.Sc.
Bruce, Robert, M.Sc.
Cherrington, Kenneth Edward.
Cowan, James Macmillan, B.Sc.
Desmarais, Roland, B.Sc.
Hill, Clifford Arthur R.
Hockmeyer, Geoffrey Bryan, B.Sc.(Eng.).
Hunter, Alexander, B.Sc. (Eng.).
Mackenzie, Thomas Herbert, B.Sc.
Marriott, Thomas William, B.Sc.
Mason, Thomas Hedley.
Meek, John Millar.
Morgan, Reginald Ian, B.Sc.
Mulholland, Edward Bernard, B.Sc.(Eng.).
Shearer, James Brian, B.Sc.
Smith, Alfred Stanley.
Smith, Philip Edward.
Taylor, John Leslie.
Thomas, Ivor Lewis, B.Sc. (Eng.).
Volum, William Gordon.
Watson, Thomas Henry.
Wells, Frank Herbert, B.Sc.(Eng.).
Withington, Harry.

1937

C.M.A.

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- **Liverpool Electric Cable Co. Ltd.**
- **The London Electric Wire Co. and Smiths Ltd.**
- **The Macintosh Cable Co. Ltd.**
- **Pirelli-General Cable Works Ltd. (General Electric Co. Ltd.)**
- **St. Helens Cable & Rubber Co. Ltd.**
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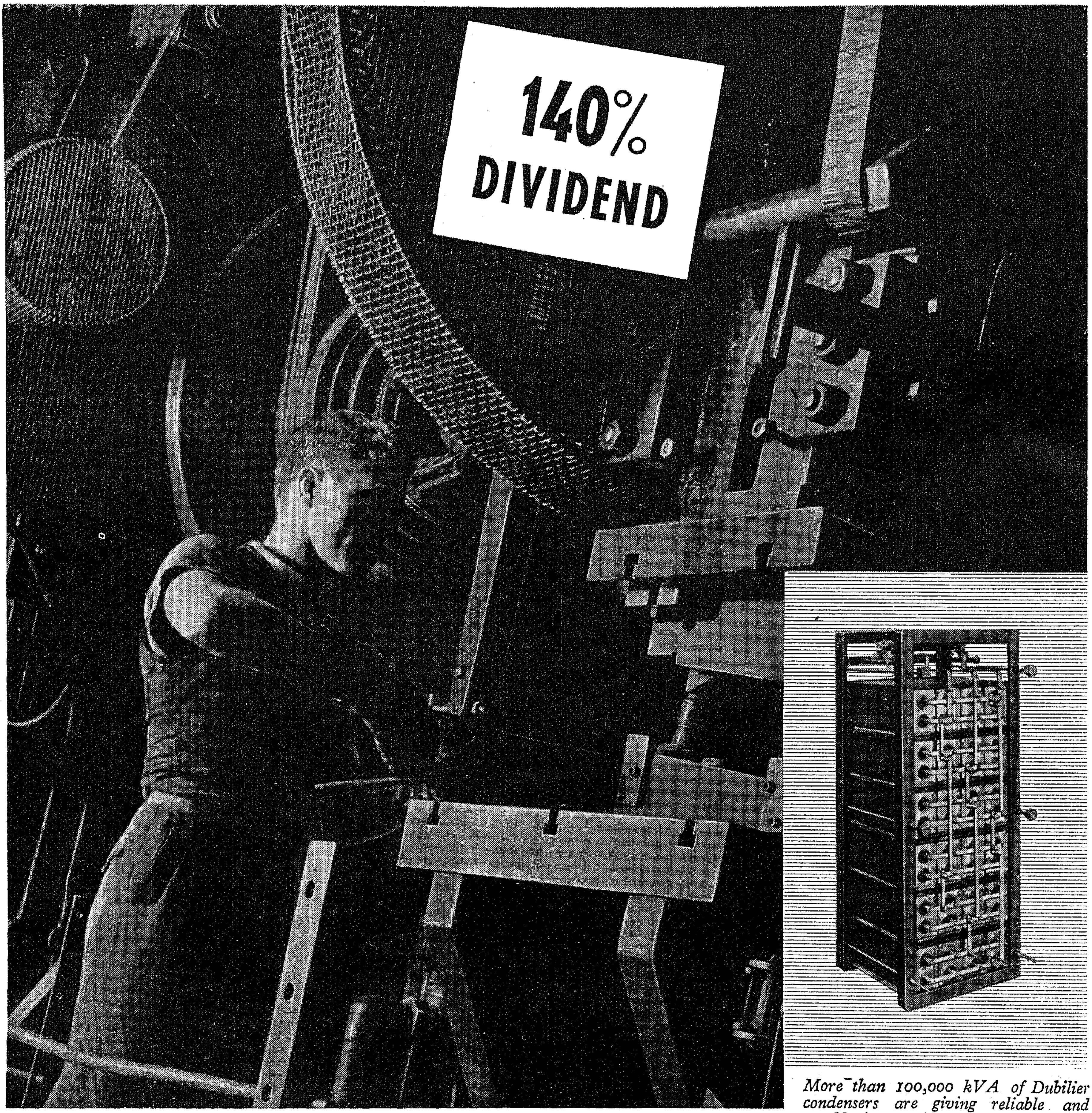

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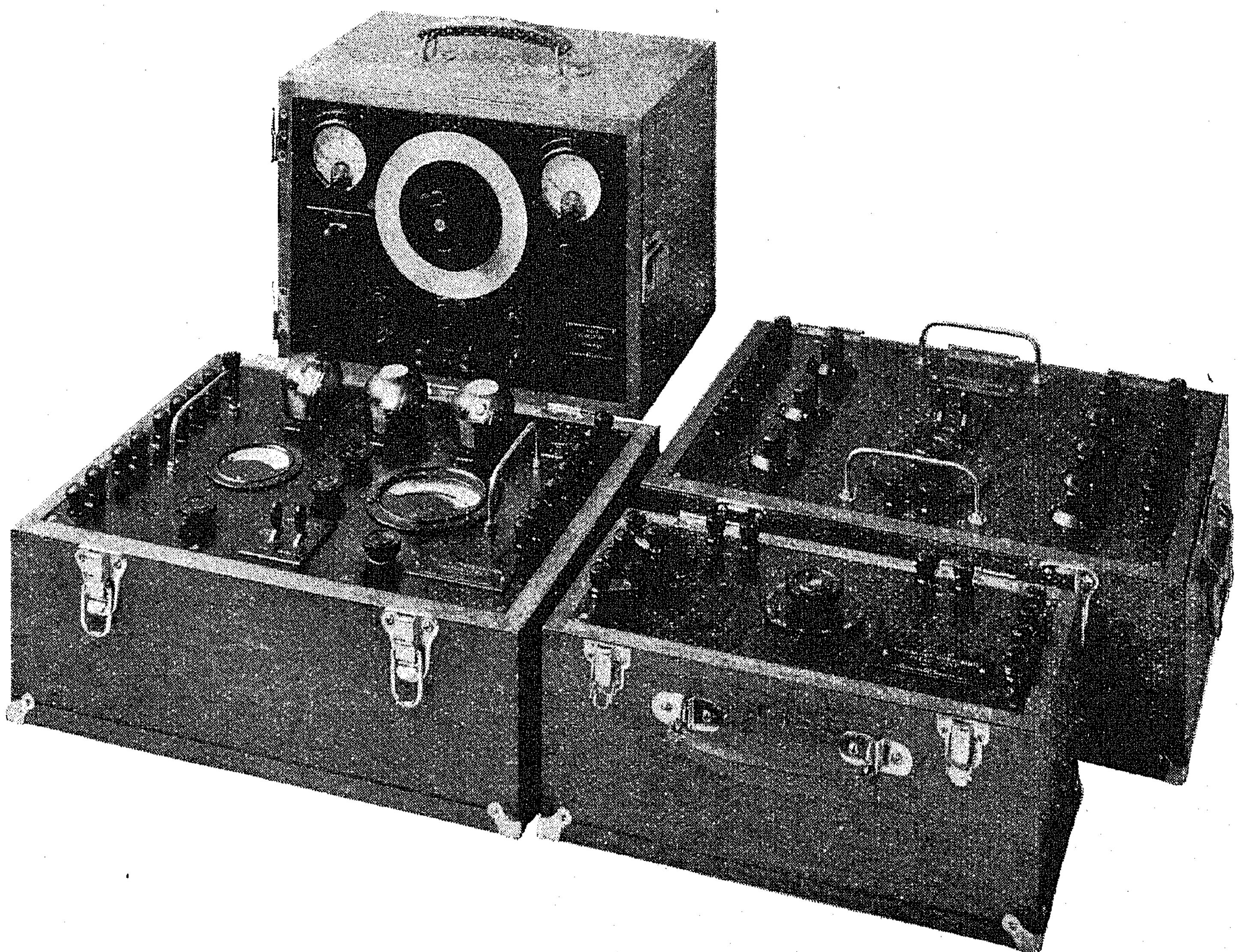

THE four portable test sets illustrated provide facilities for all the major tests required on voice frequency repeatered telephone systems, and have been largely supplied to the British Post Office as well as to Administrations abroad. The kit comprises a heterodyne oscillator, a direct reading transmission measuring set, a voice frequency line impedance bridge and a special impedance unbalance attachment. The measurements which can be made include transmission level and loss measurements, the measurement of impedance on telephone lines, and the measurement of impedance unbalance on lines and networks. As the source of tone is a heterodyne oscillator with a flat output frequency characteristic, and as the transmission measuring set has a flat frequency response and is direct reading, measurements of loss, level and impedance unbalance can be made extremely rapidly and without intermediate adjustments or calibration.

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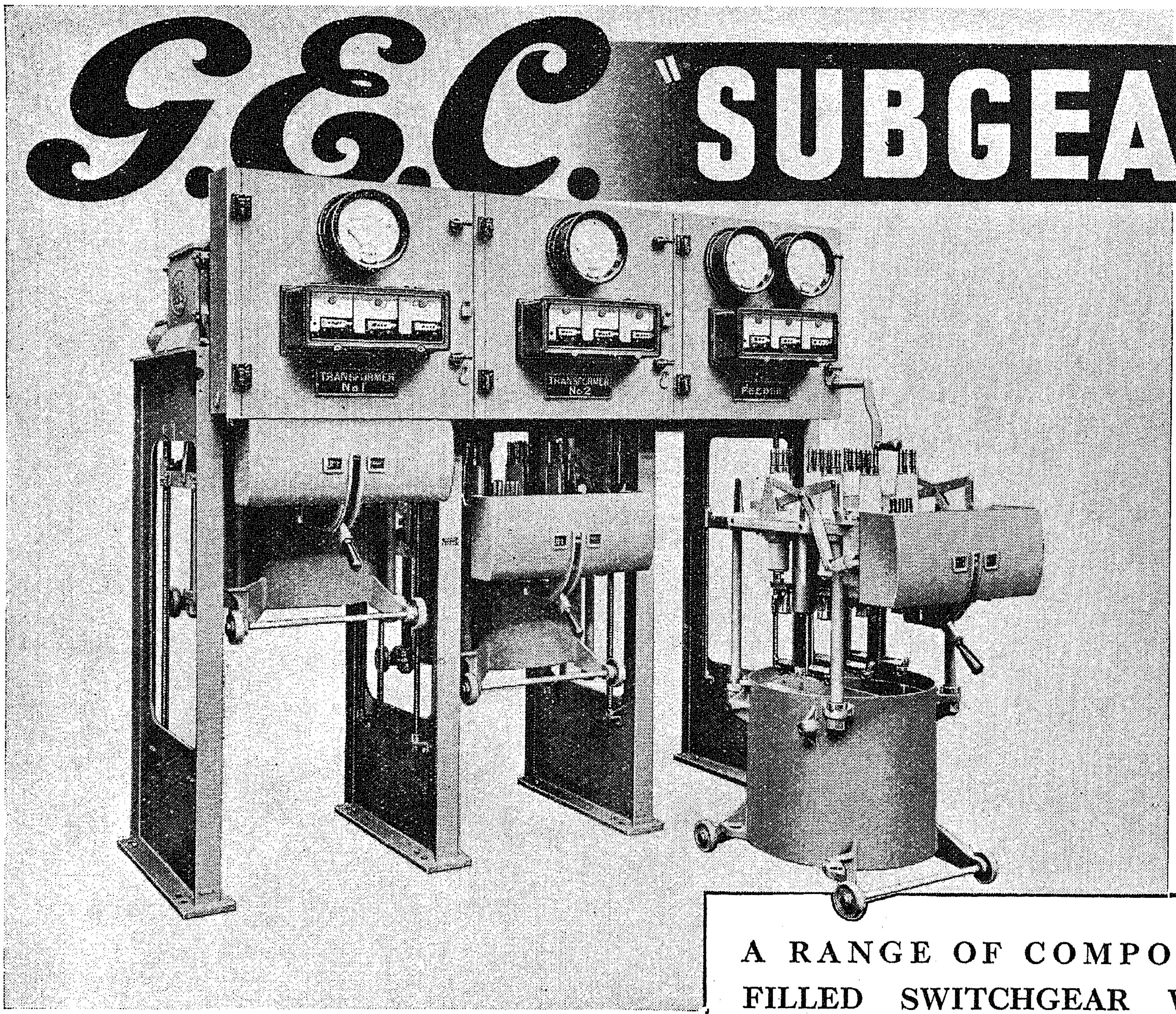

6,600 volt metalclad SUBGEAR showing one breaker in service position, one isolated and one withdrawn for inspection.

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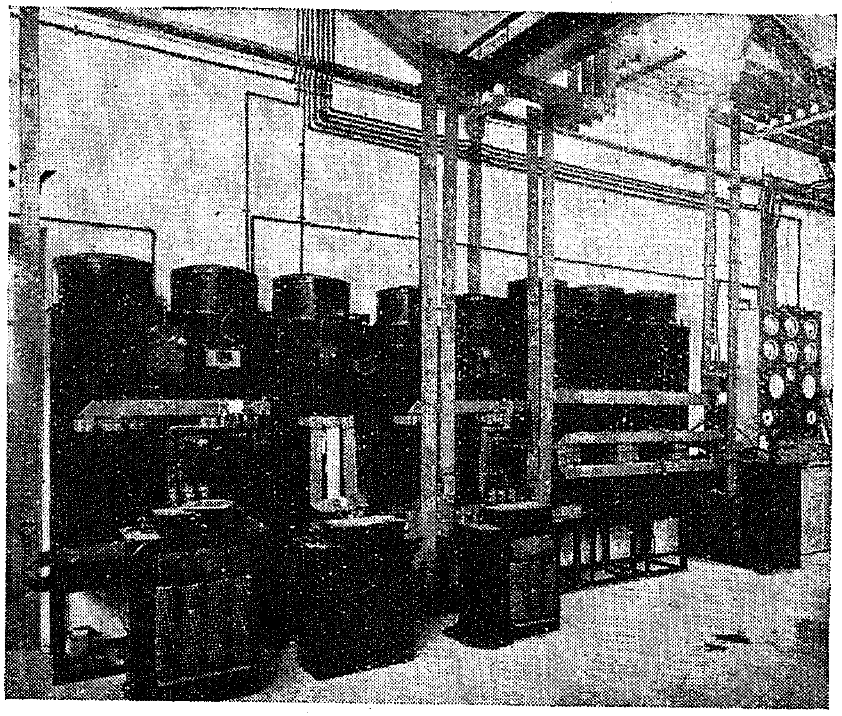

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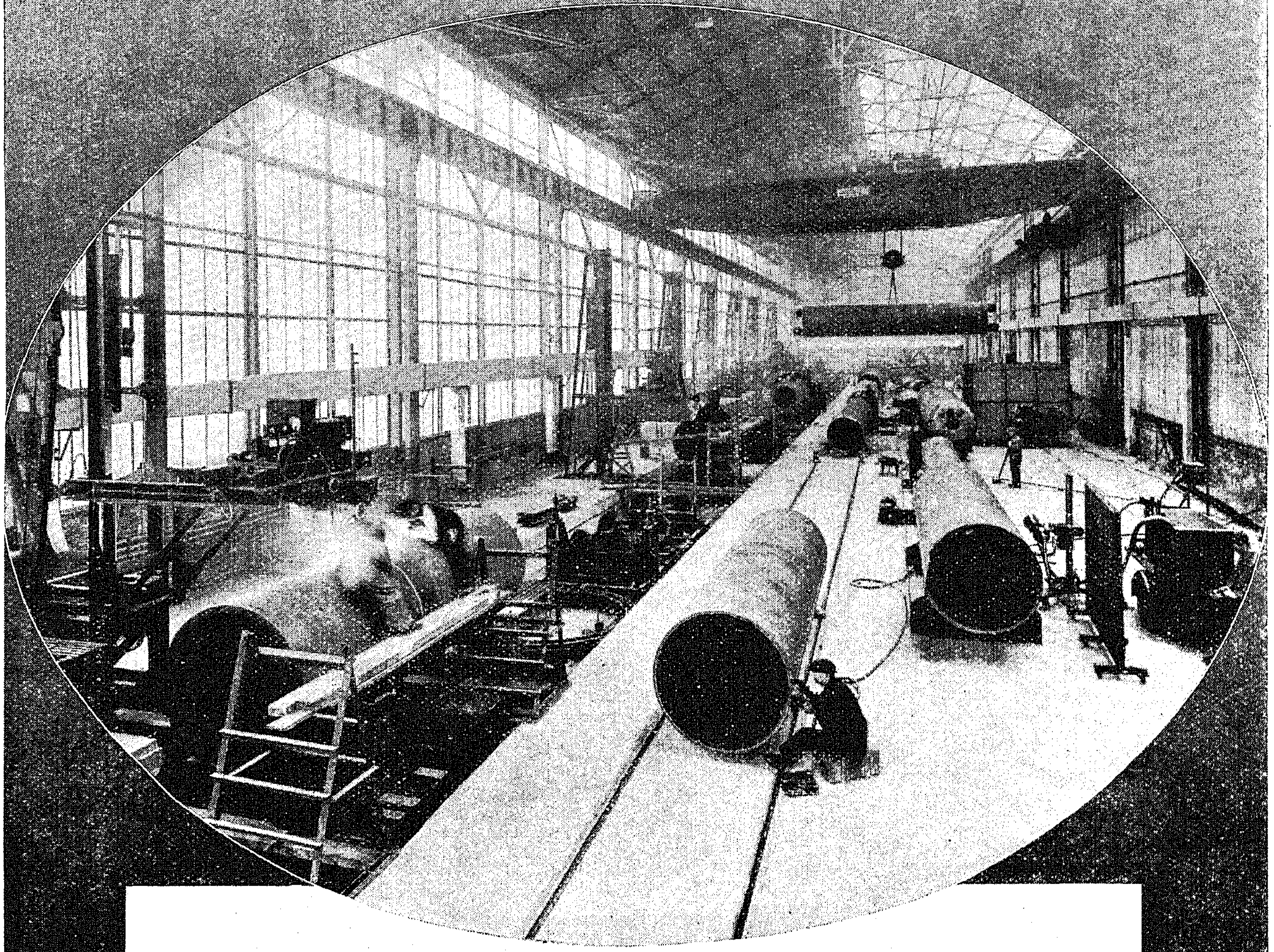

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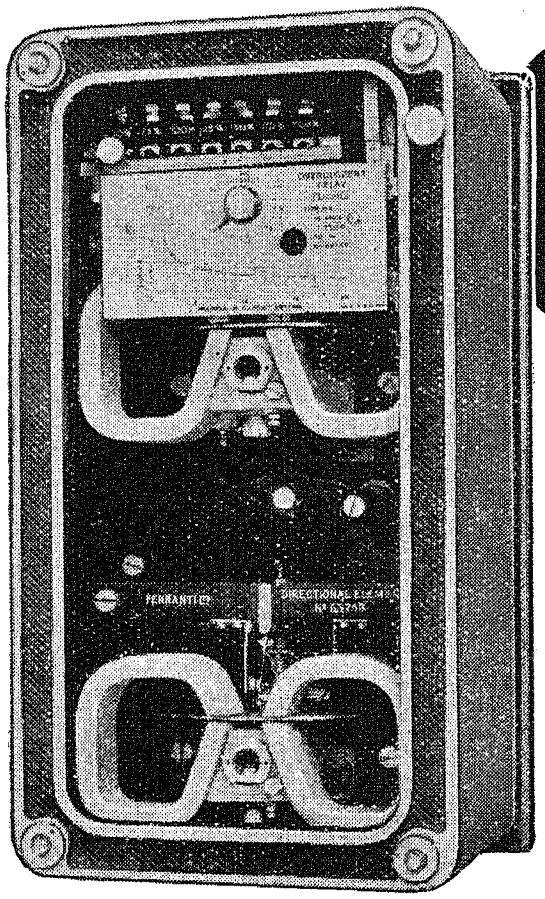

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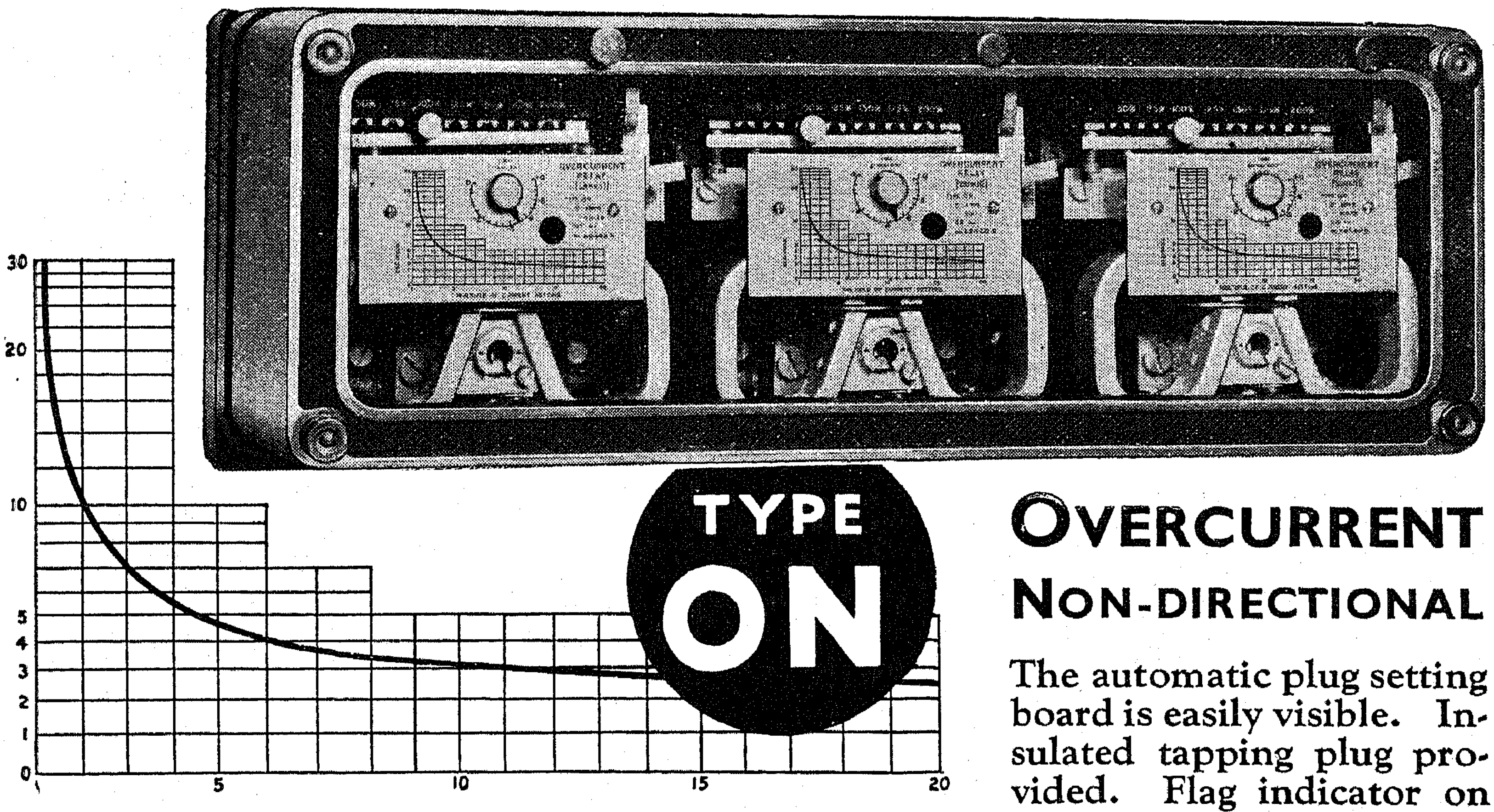

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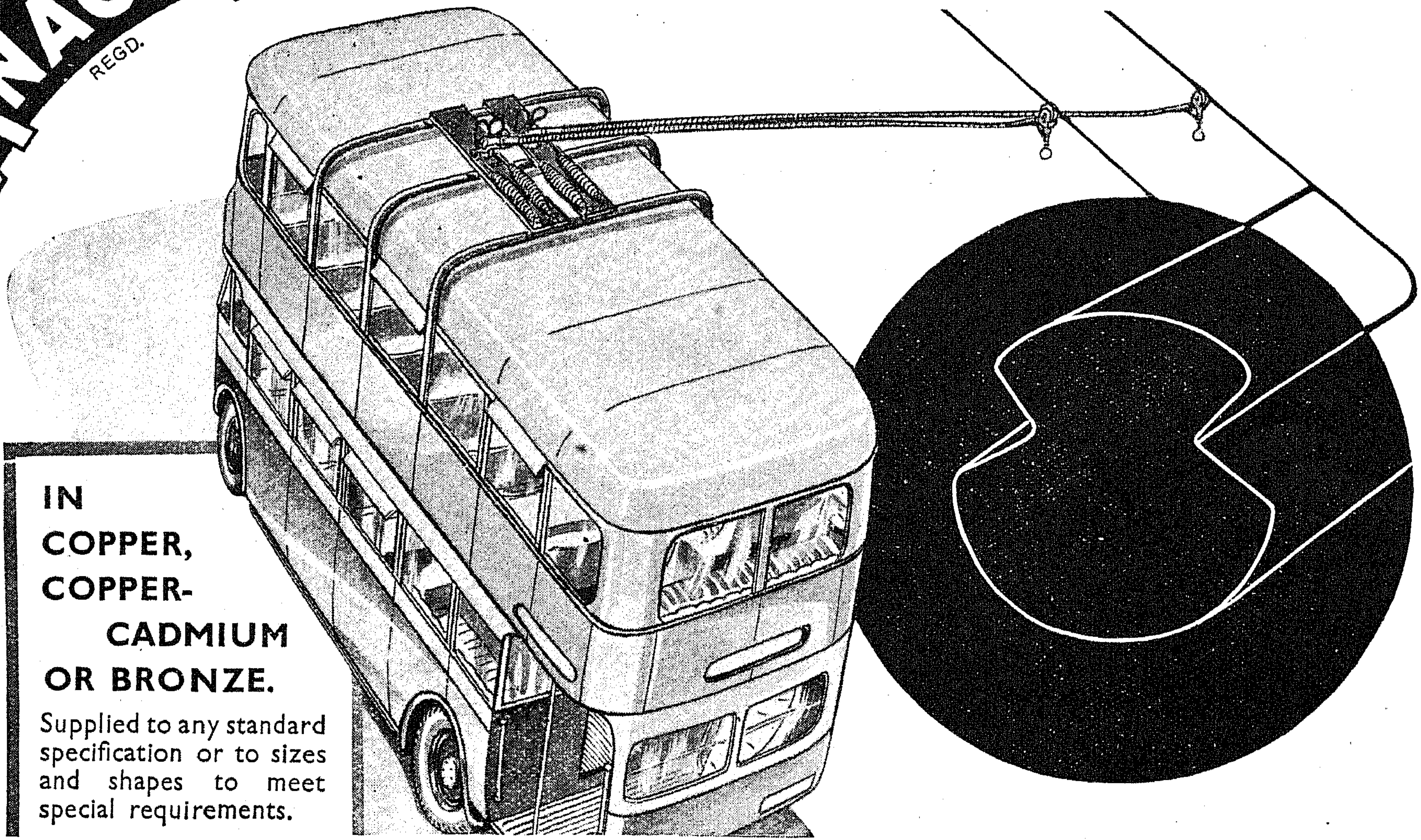

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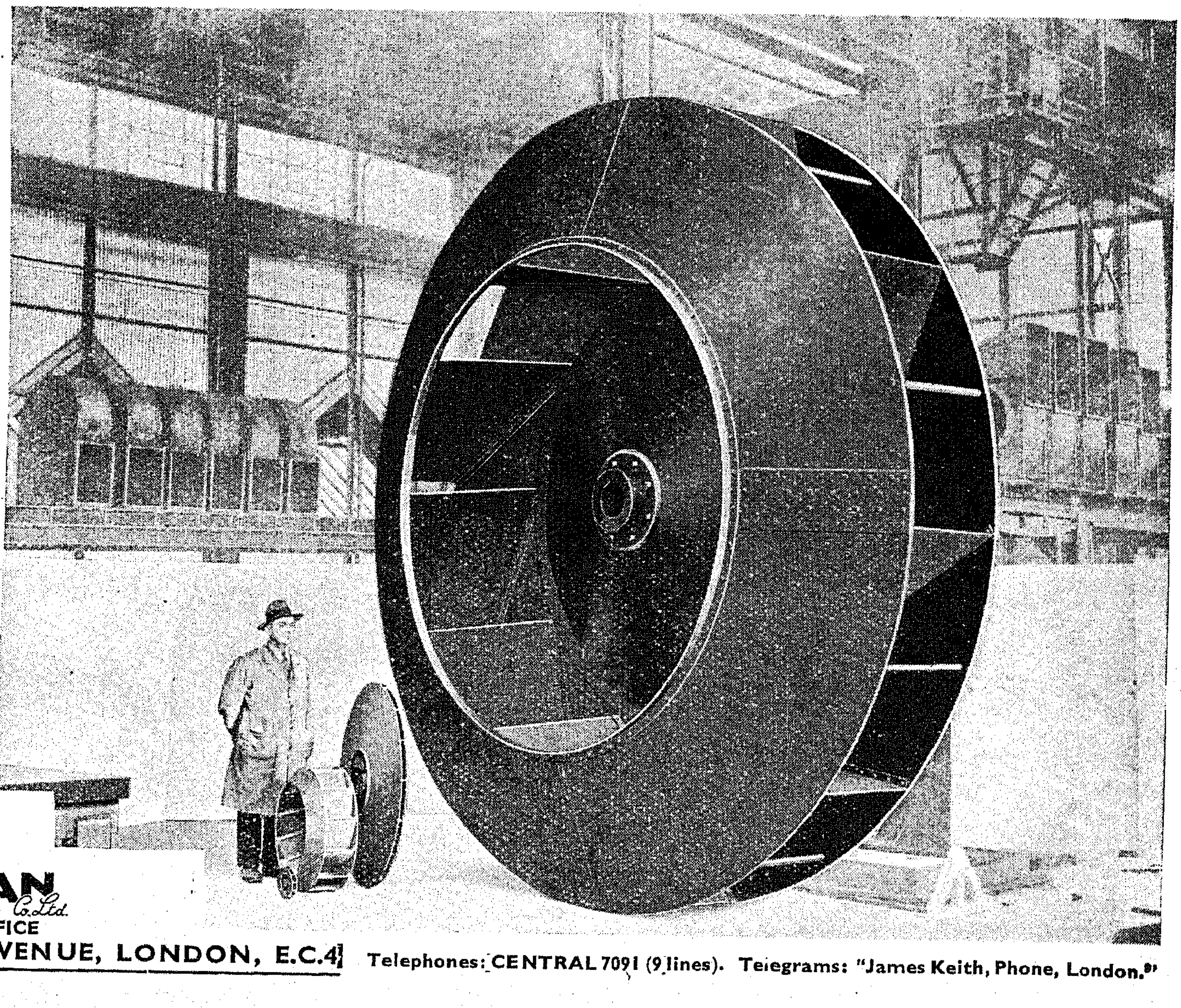

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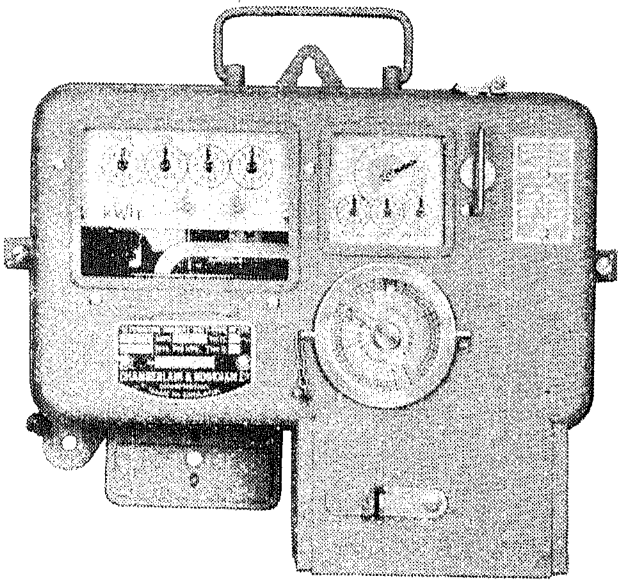

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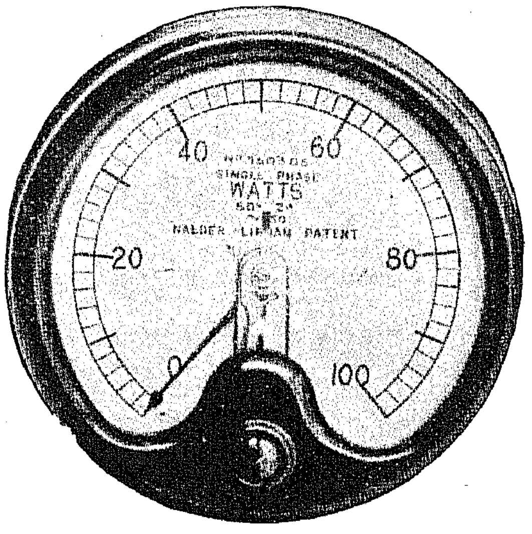

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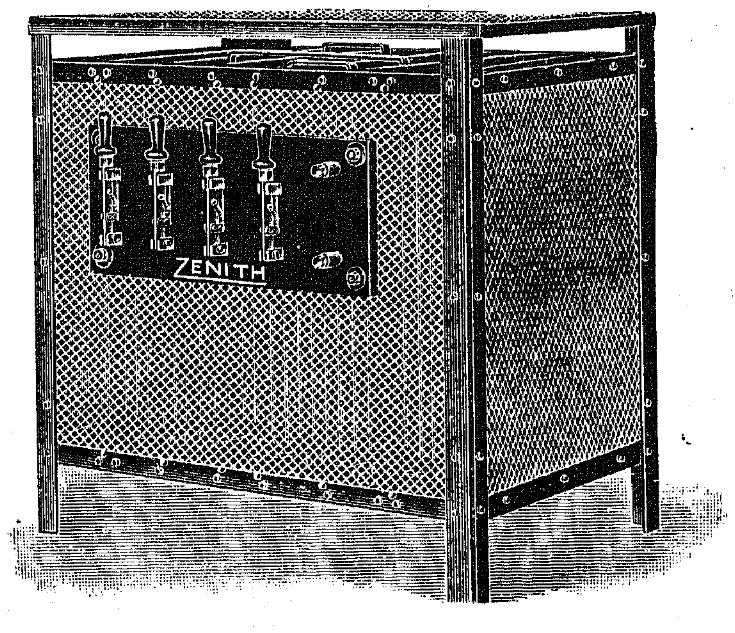

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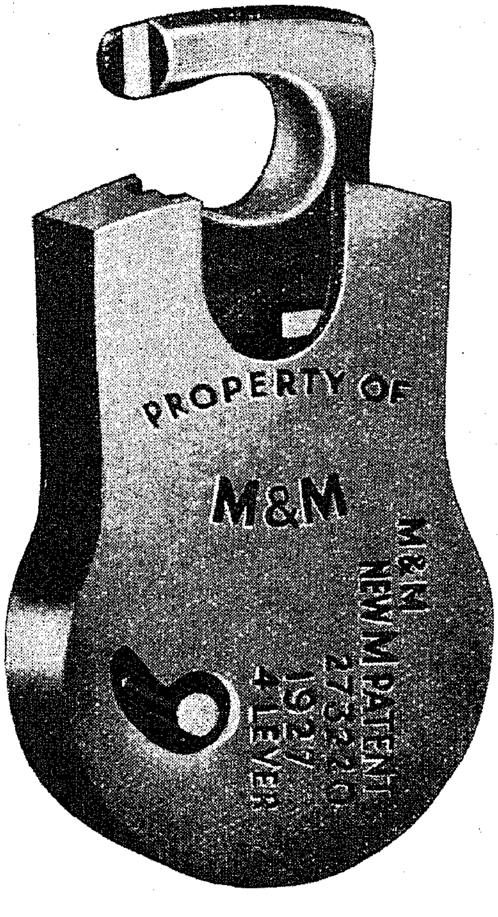

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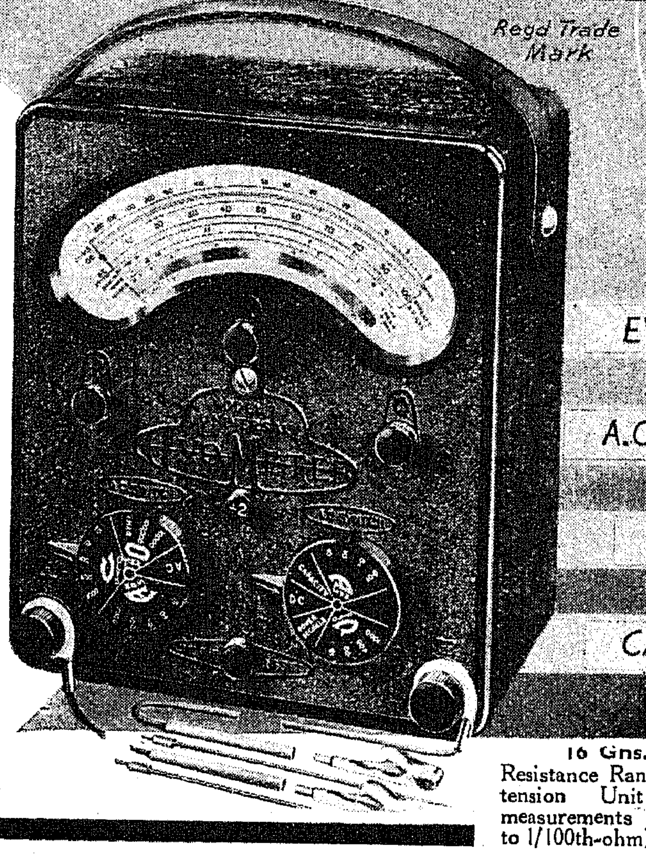

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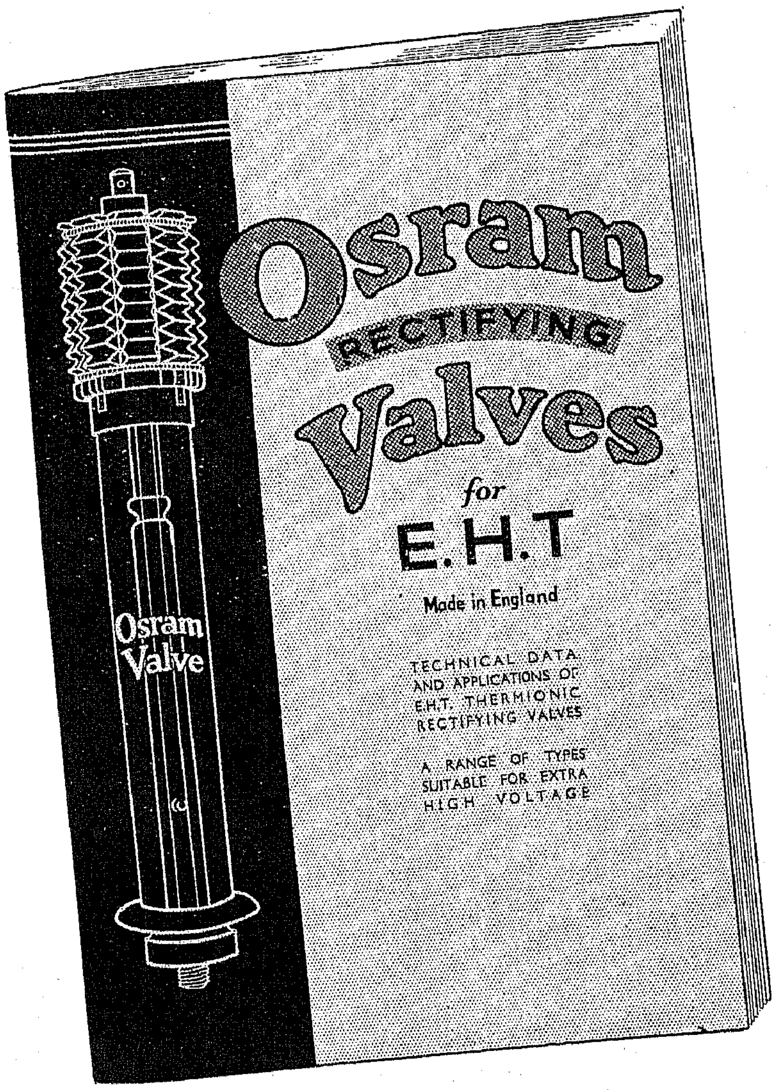

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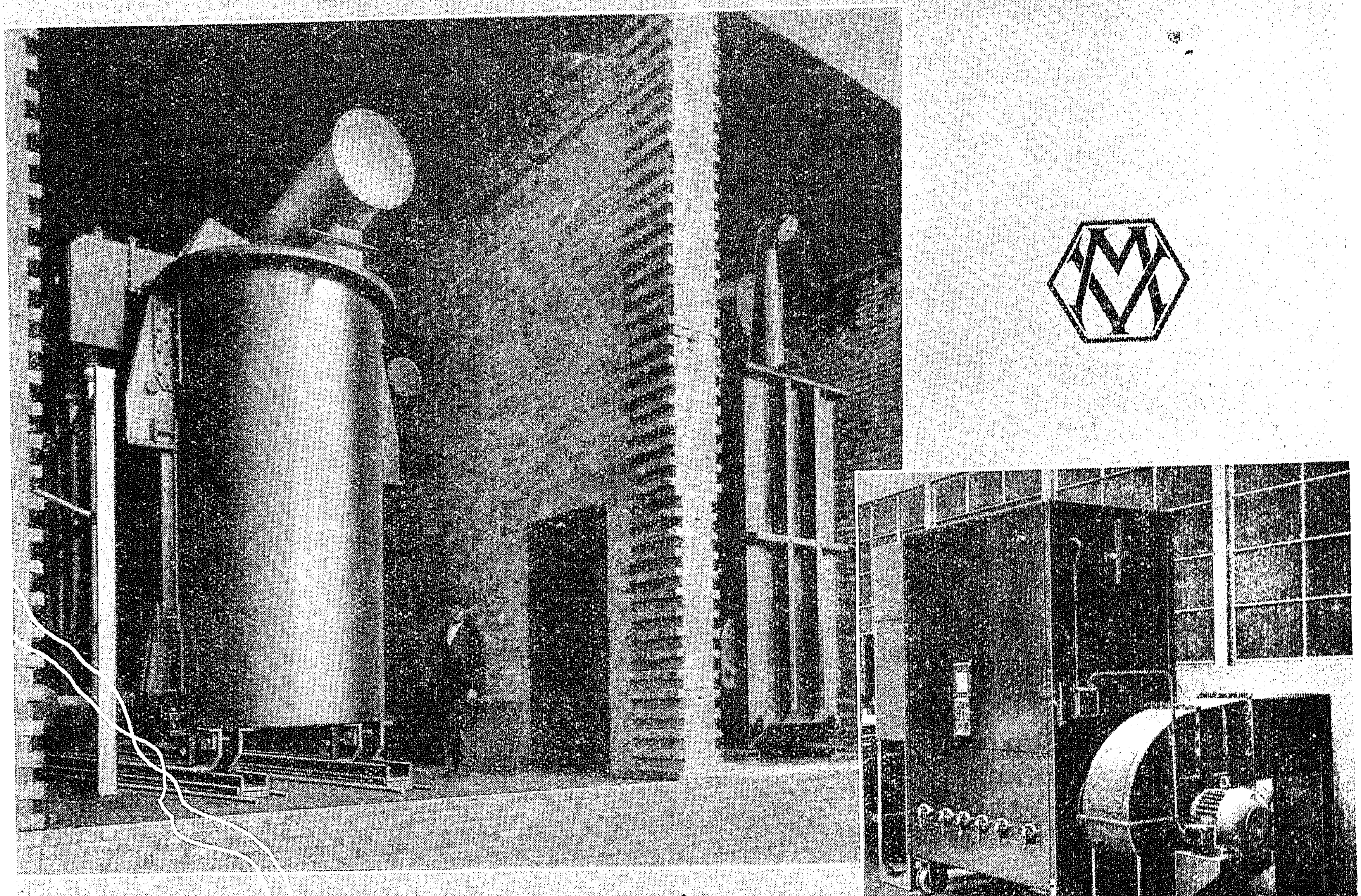

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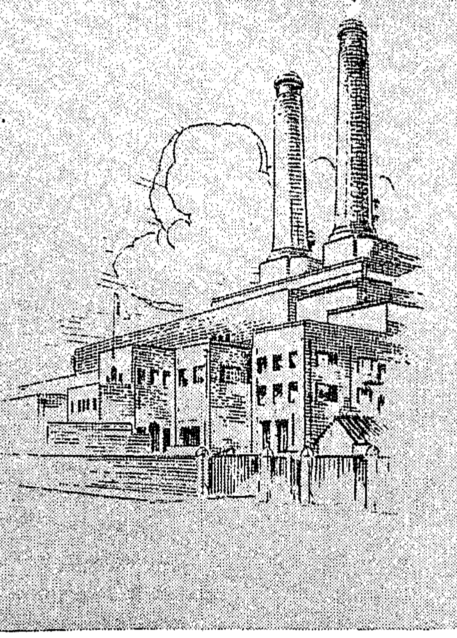

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